SEPTEMBER 1950

Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

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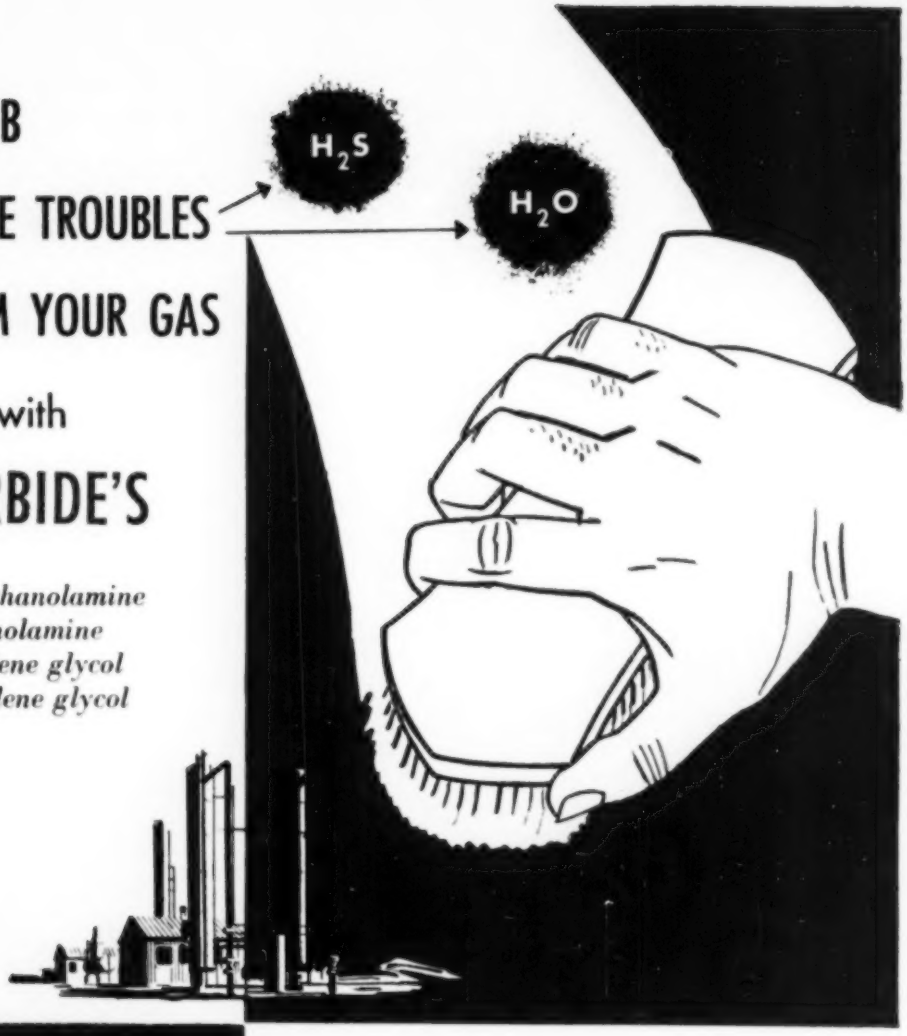

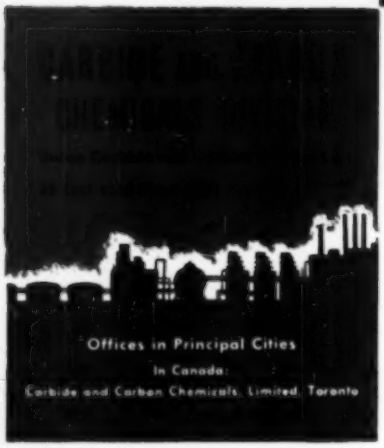

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C.E.P. begins this month the publication of the papers presented at the chlorine-alkali symposium held at the Houston meeting. Three papers are printed this month and there will be two more in the October number. Though the chlorine-alkali industry is an old one it is always coming up with possibilities for new applications.

Thomas K. Sherwood in this month's Opinion makes a few observations on the opportunities for creative accomplishment presented to chemical engineers and on their responsibilities for producing the new ideas that result in worthwhile causes.

While C.E.P. has no regular Letters to the Editor department we are always willing and anxious to present discussion that is pertinent to our profession. We have not formalized such a page simply because the volume of letters on worthy subjects has not been great enough to make it a monthly feature.

The eighth annual report of the A.E.C. is off the press and is available from the Government Printing Office at a cost of $.55. The major portion of the report deals with the control of radiation hazards in the Atomic Energy Program. Odd facts tumble out of its pages; one, also noted in this month's item of the beginning of the Brookhaven pile, is that residents of the Rocky Mountains get more radiation from cosmic rays than the average worker in an A.E.C. installation. Another fact, completely new to us, is that three atomic bombs were exploded by the A.E.C. at its Eniwetok tests, all tower explosions as at Alamogordo.

The 43rd annual meeting of A.I.Ch.E. will take place in December in Columbus, Ohio. Watch next month's issue for the preliminary program and arrangements. There will also be a post-meeting account of the Minneapolis meeting.

Are you looking for a supervising chemical engineer? A Ph.D. is available. Or do you want an industrial research group leader? Look up our Classified Section this month.

Volume 46 Number 9

Chemical Engineering Progress

SEPTEMBER 1950

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See General American for

CREATIVE DEWATERER ENGINEERING

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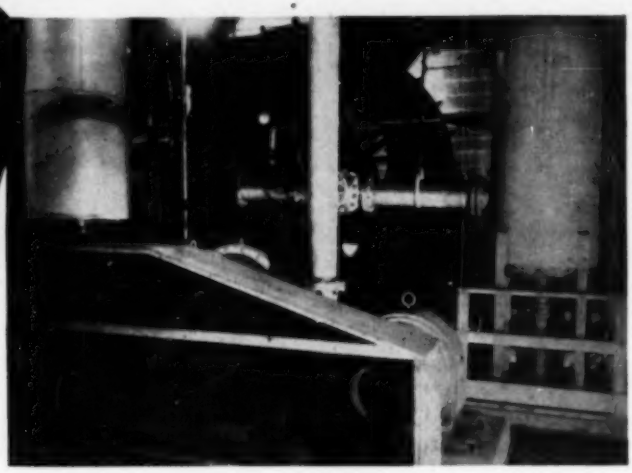

OPERATORS everywhere report highly successful results with the Conkey Rotary Hopper Vacuum Dewaterer for a wide range of materials. Some of these include aluminum tri-hydrate, barium nitrate, ground pitch, silica sand, coal, grain, TNT, Ilmenite, paper stock, gun cotton, abrasives and magnetite.

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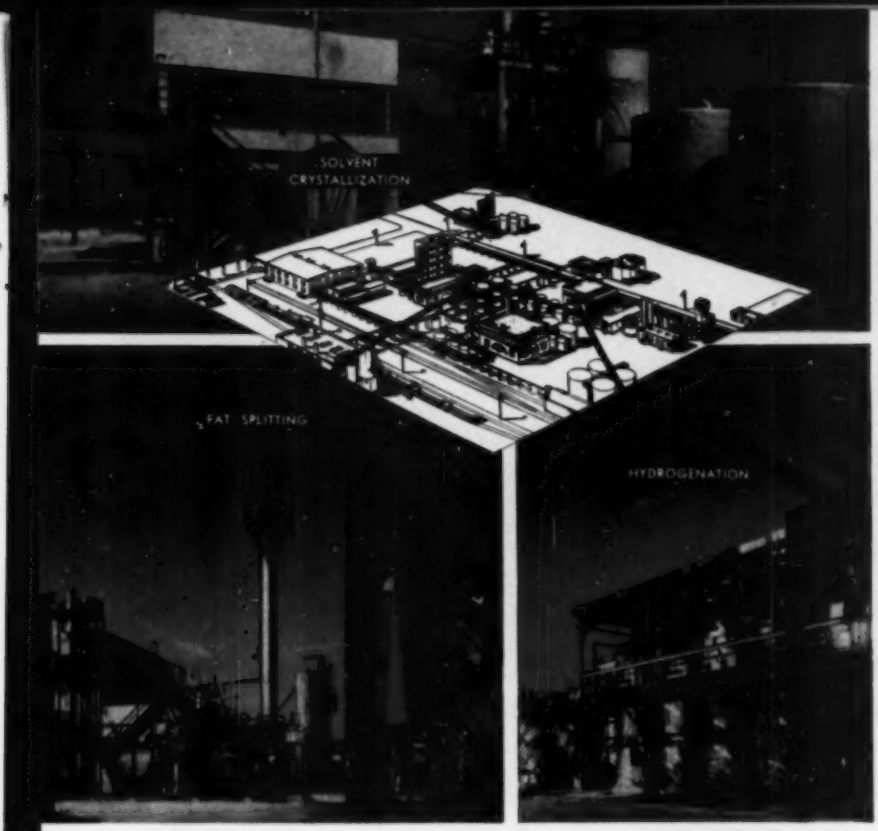

A New Process For Separating Fatty Acids by Fractional Crystallization

ANOTHER BADGER FIRST

The Fatty Oil Fractional Crystallization Process utilizing solvents as a means of separating fatty acids offers the industry an opportunity to make a wide variety of products of high purity and excellent yield at low operating cost.

A new Fatty Acid Fractional Crystallization unit, engineered and constructed by Badger, is now in successful operation at Armour's McCook, Illinois plant. This unit permits separations with solvent over a wide range of operating temperatures. As a result, a variety of charge stocks can be processed and products of widely divergent characteristics manufactured.

This is a part of Armour's integrated plant for processing of animal and vegetable fats, designed on the basis of developments and extensive experience of Armour and Texaco, and engineered and constructed by Badger with the exception of three specialized units furnished by others. Among the Badger-built units, as well as the crystallization unit, are installations for fat splitting, hydrogenation, refining and bleaching, product finishing and a boiler house, waste recovery system, tankage, warehousing and shipping, and all auxiliary facilities.

The Fatty Oil Fractional Crystallization unit is operated under license from the Texaco Development Corporation. Into this unit Badger has built the "know-how" of both Texaco and Armour. This is another example of Badger's unique ability to convert basic design of a new development into a successful commercial plant.

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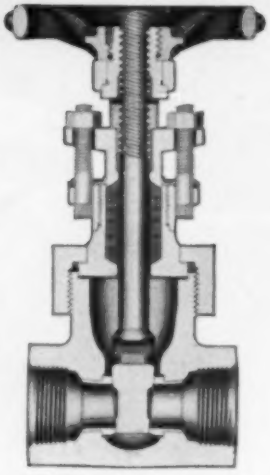

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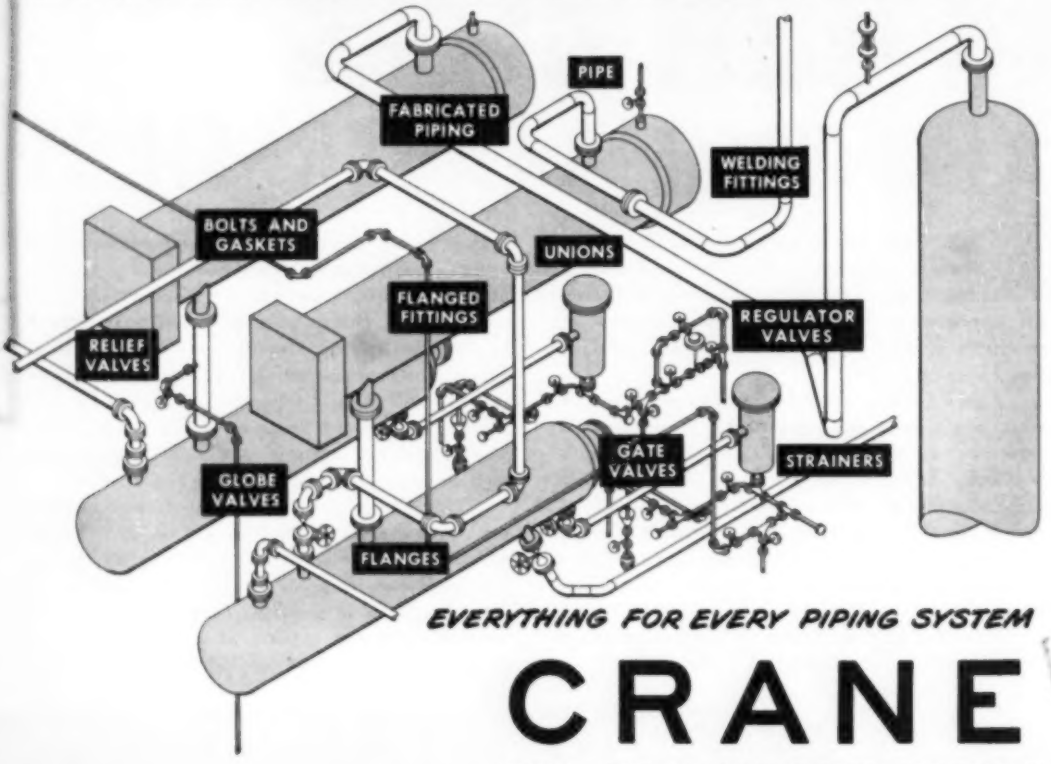

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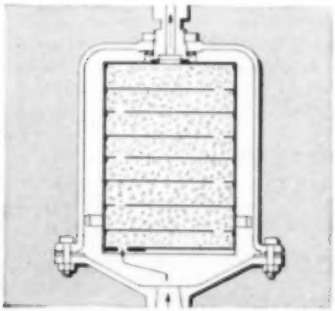

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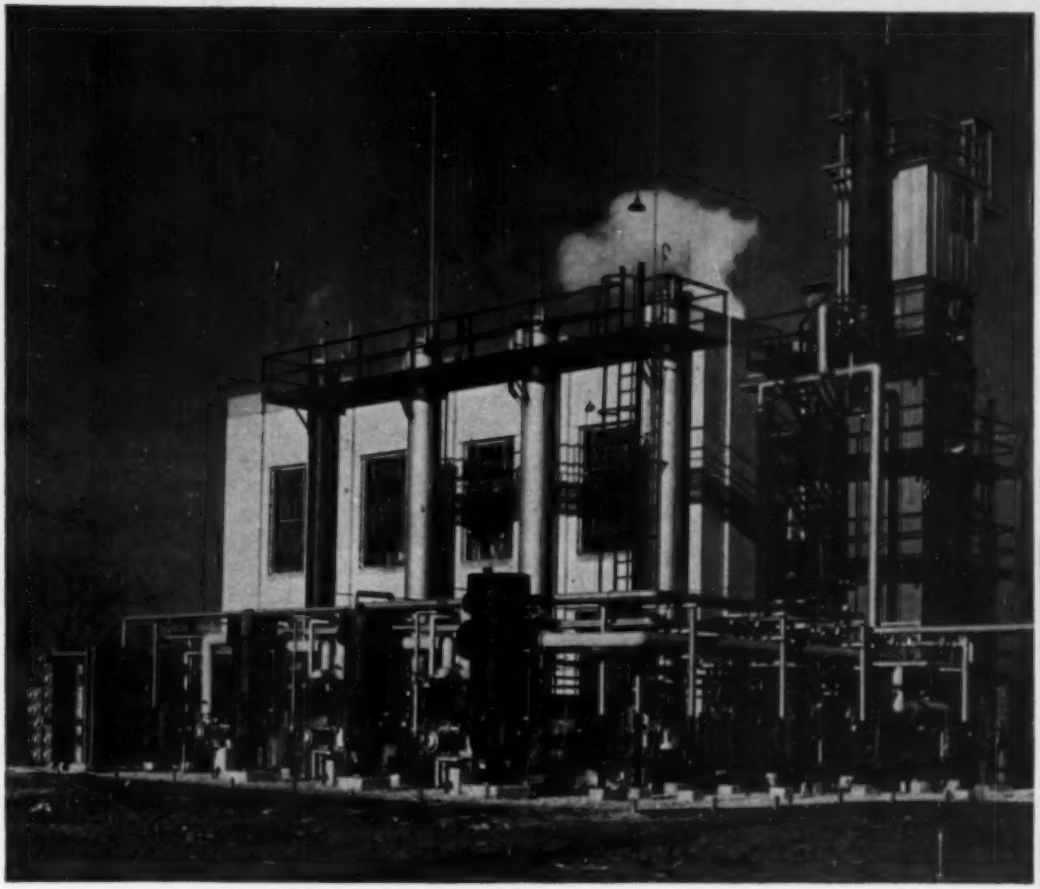

Lever Brothers Company, too, gets hydrogen at low cost

ALMOST every hydrogen plant built during the past five years in the United States for fats and oils processors has been a Girdler HYGIRTOL* plant. A recent installation, shown above, is the Hammond, Indiana plant of Lever Brothers Company.

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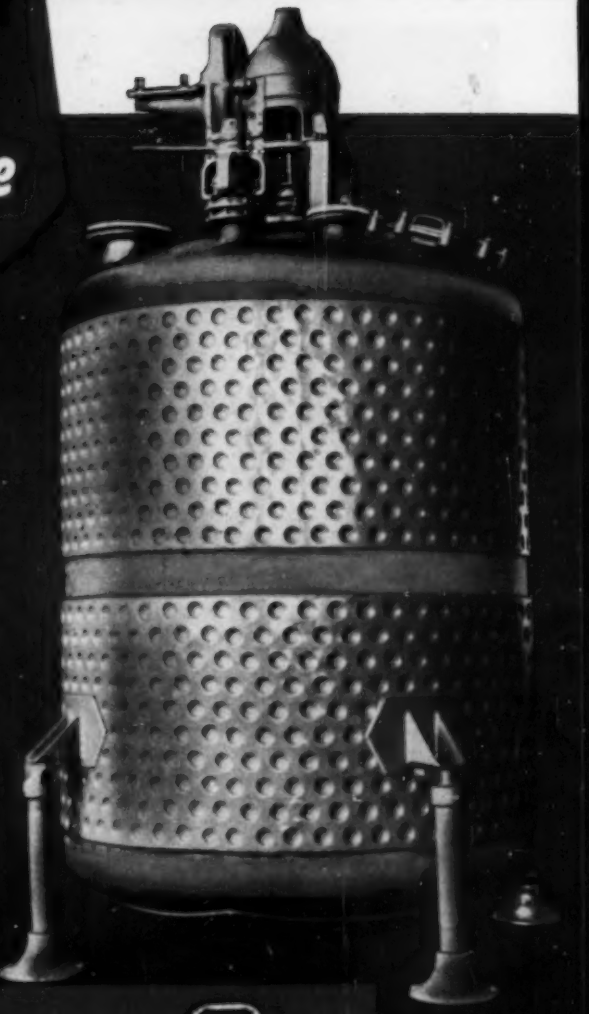


Why it pays to check with Pfaudler on your custom-built process equipment requirements

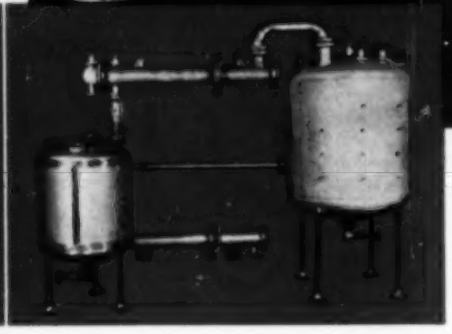
Just about 46% of the processing requirements for Pfaudler equipment are met by standardized stainless steel and glass-lined steel units. Pre-engineered and built on a production basis, this equipment makes possible substantial savings in both price and delivery—all of which are passed on to you.

Pfaudler does not stop there, however. When standard designs won't meet the capacity, pressure, or other requirements involved, you obviously need something special. On this work Pfaudler offers similar design advantages that can mean real savings to you.

For example, the large stainless steel reactor shown above would have cost far more had the jacket been built in the conventional way. Instead, Pfaudler engineered a "dimpled" jacket which permits higher pressures *without* a commensurate increase in steel thickness of relatively high priced alloy. Thus, the purchaser got more for his money without any sacrifice in performance.

You see, Pfaudler engineering groups are specialized in the fields of processing, corrosioneering, design and fabrication. All work together, give you more for your money *plus* better performance. Send us your bids!

Regardless of how specialized your processing requirements are, Pfaudler is well qualified to offer sound construction with maximum economies.



The "dimpled" jacket construction on this special stainless steel reactor saved over $400.00 in material costs alone.

Pfaudler

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OPINION AND COMMENT

CREATIVE ACCOMPLISHMENT

RESULTS of a poll some two years ago indicate that chemical engineers are among the happiest of married men. This may mean that they are happy because they are chemical engineers rather than because they are married, but why should chemical engineers be happy, married or unmarried?

There are evidently many reasons for human happiness, but among the most important and most valid is a feeling of accomplishment. The man who calculates the value of pi to five hundred significant figures or determines that the word "California" can be put together to form a hundred or more English words has a feeling of accomplishment, but such activities do not present an attractive formula for happiness. I suggest that the chemical engineer finds happiness through accomplishment of a special variety, namely *creative* accomplishment.

The boy who builds a clubhouse in a tree gets something of the thrill of creative accomplishment, which he misses in successfully memorizing a poem. The guard at the plant gate does not get it, nor does the train conductor, nor even the musician who plays but does not compose. The architect, the scientist, and the engineer, however, are permitted the happy experience of seeing their plans develop and bear fruit, of seeing successful buildings, processes, and enterprises take shape and grow from the seedling ideas which were their own. Theirs is the thrill of creative accomplishment.

If we are men of good will, we will be unhappy if our work is not for a worth-while cause. We are fortunate that our natural professional activity is for good purposes. A few of us work to develop atom bombs, but even these do so in the conviction that their work is in the defense of freedom. Most of us work with things and people for constructive purposes, in order that there may be new things for better living—in order that one company may report an annual sales volume of more than a billion dollars in products which were not made commercially in 1928. This is creative accomplishment.

But there is another side to this. Those of us who work in the fields of research and development are privileged to be close to nature, to understand better than our fellow-men that there is a basic order in natural phenomena, and that man has this gift of understanding. Now and then we have the priceless experience of learning something new and important about nature, of discovering a new chemical reaction, or a correlation of jumbled facts. Stanton and Pannell had the thrill of creative accomplishment when they discovered the general correlation of friction data for the flow of oil, water and air in pipes. This is the kind of creative accomplishment shared by many chemical engineers in the course of their normal professional activities.

The principal difference between secondary school and college, other than the increasing complexity of the factual material taught, ought to be the opportunity and obligation of the college to give the student some concept of the thrill of creative accomplishment. The college is at fault if the students are not exposed to the opportunities for happiness through creative professional work. Students will get this idea only if the college has a *creative atmosphere*—a group of professors themselves actively and enthusiastically engaged in creative work—an atmosphere of drive, initiative, and accomplishment. Engineering colleges, in my opinion, should be required to provide this creative atmosphere if their curricula are to be accredited.

Creative accomplishment, as here defined, is evidently more difficult in some fields than in others. The botanist, the mineralogist, and others who are required to spend a great deal of time classifying facts, must find it difficult to make original contributions. Chemical engineers, with training for creative accomplishment in both science and engineering, have wider opportunities than most. We have both the greater opportunity and the greater responsibility for producing new and better ideas, theories, concepts, processes and products.

"God created man in his own image . . . and God blessed them, and God said unto them, be fruitful and multiply, and replenish the earth, and subdue it." We are "in his own image" if we are creative, and we participate in subduing the earth if, as engineers, we assist in "harnessing the forces of nature for the benefit of mankind." Few things make for greater happiness than success in such endeavors.

Thomas K. Sherwood

New Louisville Chemicals Dryer costs less, does 50% more work . . . at 77% less operating expense

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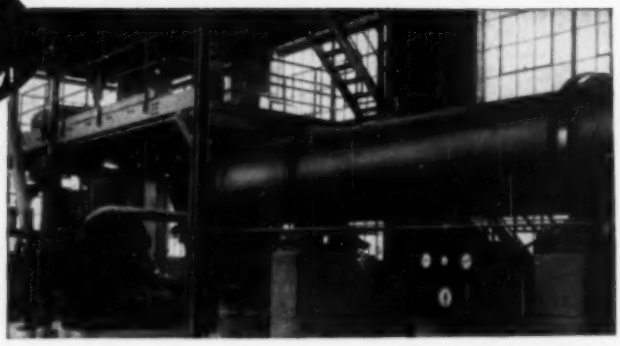

FORMER DRYER

Installed cost	$40,000
Annual production (tons)	6,000
Drying cost per ton	3.72

(space required, 1500 sq. ft.)

LOUISVILLE DRYER

Installed cost	$20,000
Annual production (tons)	9,000
Drying cost per ton	0.83

(space required, 500 sq. ft.)

YEARLY SAVINGS of LOUISVILLE DRYER in OPERATING COSTS ALONE $14,850

Other General American Equipment: Turbo-Mixers, Evaporators, Thickeners, Dewaterers, Dryers, Towers, Tanks, Bins, Pressure Vessels

A magician's creation? No! The Louisville Dryer described here was installed by a chemical processor after his production was completely analyzed by a Louisville engineer. By using advanced, complete knowledge of drying processes, this dryer was especially designed to fit into his production line after the dryer's performance was pre-determined in our own unique research laboratories and pilot plant.

Without obligation ask a Louisville engineer to survey your drying methods. He may come up with a better solution that costs you less for faster, more satisfactory production.

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The chlorine-alkali industry is old, very old, yet research workers in this field are ever searching for more economic means of production and seeking to extend the applications of techniques . . . at the Houston meeting a symposium on the subject was held and this month C.E.P. prints three of the papers presented . . . one, discusses possibilities in the science of using metal amalgams for producing caustic alkalies, and metals such as potassium and lead . . . another paper tells of a method for producing chlorine without the necessity of manufacturing caustic soda and a third, tells of optimum size and current rating of Hooker chlorine-caustic electrolytic cells . . .

OPTIMUM OPERATING CURRENTS FOR HOOKER TYPE S CELLS

DEANE O. HUBBARD

Project Engineer, Hooker Electrochemical Company, Niagara Falls, New York

THE trend in the design of chlorine-caustic electrolytic cells has been in the direction of larger units. Some earlier cells were designed for 1000 to 1500 amp. Today most of the electrolytic chlorine-caustic plants are using cells designed for higher operating currents. One French company is starting a plant early in 1950 with 50,000 amp. mercury cells, which is believed to be approximately twice the size of the largest cells in operation in this country.

At various times, the Hooker Type *S* cell has been evaluated in comparison with smaller cells and with larger cells. It was found to be more economical to use the Type *S* cells, at 8000 to 10,000 amp., in plants as small as 5-ton capacity/day than to use smaller cells. Furthermore, these calculations indicated that in plants of about 50 tons/day and larger a 20,000-amp. cell could be more economical than a 10,000-amp. cell. On that basis the Hooker Type *S*-3 cell was designed with twice the active electrode areas of the Type *S* cell.

General Design of Hooker Cells. The Type *S* cell was originally designed to operate at 6000 amp., which was considered to be its most economical operating current at that time. Subsequently, with changing cost conditions its rating has been increased to 7500 amp., with operation recommended up to 10,000 amp. It has been operated continuously at currents up to 12,000 amp., although that is not recommended.

The basic design of the Type *S* cell (Fig. 1) consists of rows of graphite anode blades mounted vertically in a concrete bottom. Flat wire screen envelopes extend inward from two sides of a rectangular channel frame like fingers, properly spaced to fit between the rows of anode blades forming the cathode. The diaphragm is of deposited asbestos fiber on the cathode.

The Type *S*-3 cell (Fig. 2) follows the same basic design of the Type *S* cell. Its active anode and cathode area is each approximately twice those of the smaller cell. The increase in size has, of course, necessitated some modification of details, but the general approach to a cubical design, which has been found desirable, has been maintained. Since the Type *S*-3 cell was designed for 20,000-amp. operation, the leads and conductors were sized accordingly.

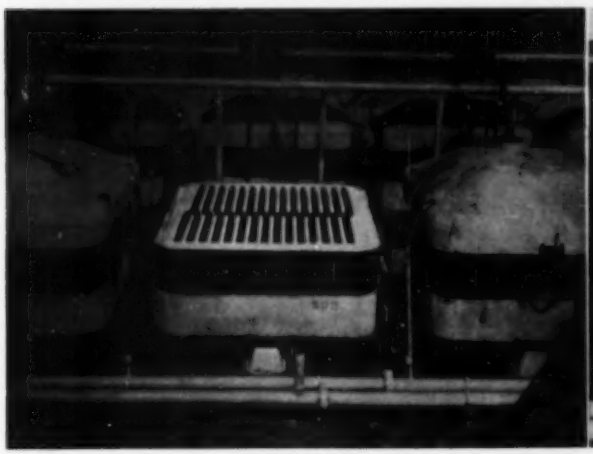

Fig. 1. Hooker Type S Cell

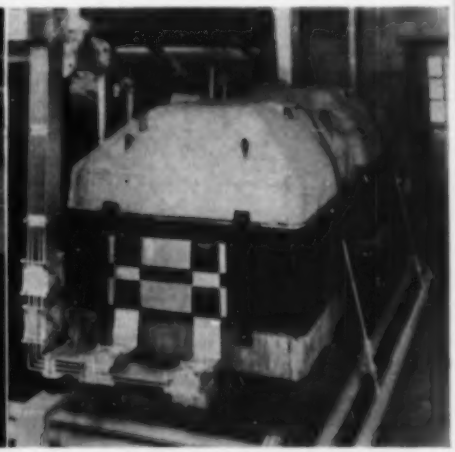

Fig. 2. Hooker Type S-3 Cell

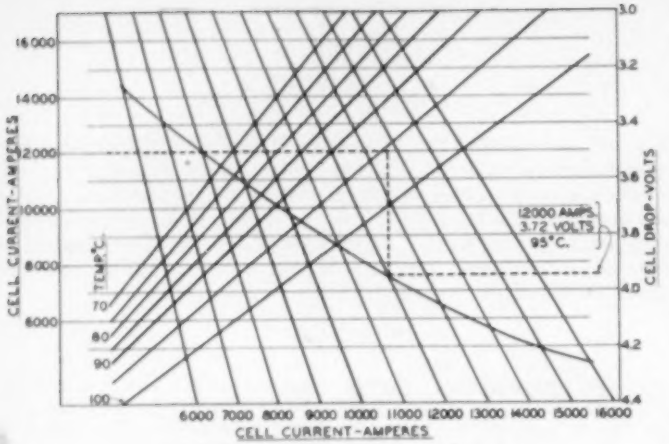

Fig. 3. Type S Cell Characteristics

Economic Evaluation. The return on the investment is the ultimate goal of an industrial enterprise and, therefore, the logical basis for developing the relative merits of the two sizes of cells and establishing their optimum operating currents. The best cell and optimum current are, of course, those which produce the highest return on the investment. Operating costs deducted from the value of the products give the profit or return. The profit per year divided by the capital investment, which is usually expressed as a percentage, is the return per year on the investment. In comparing two or more types or sizes of equipment there are certain items which would be constant for all of the cases considered. Such costs when included in a comparison add to the work without affecting the result and are, therefore, better if omitted. In this study such items as salt, chlorine-handling costs and evaporation investment are constant for a particular plant size, but since a comparison of the relative costs of plant size is not considered in this paper those items can be eliminated.

Method of Calculation—Capital Investment. For convenience, the plants are all rated in tons of caustic soda produced at the cells. With each ton of caustic soda produced, 0.89 tons of chlorine and 50 lb. of hydrogen are also produced.

To facilitate various studies, particularly in extrapolations, the graphs (Figs. 3 and 4) were developed by a combination of theoretical and experimental data involving a complete heat balance on the cell. Extrapolation for the Type *S* cell from 8000 amp. to 12,000 amp. on the graph and subsequent confirmation by actual operation have proved the accuracy of the method and figures. An equivalent graph developed for the Type *S*-3 cells, prior to their construction, required only minor adjustments in the average cell operating line. Experience has proved that reliable results are obtained by this method of extrapolation. The curves are developed for standard operation with 324 g./l. brine feed at 70° C., producing a cell liquor containing 1350 lb. NaCl/M lb. caustic soda.

The average cell voltage and average cell temperatures of Table 1 are obtained from Figures 3 and 4. From numerous tests and theoretical evaluations it was found that the loss in current efficiency of the Hooker cells is inversely proportional to the operating current. Using 4% loss in current efficiency (96% current efficiency) at 8000 amp. for the Type *S* cell and at 16,000 amp. for the Type *S*-3 cells, loss in current efficiency at other currents is easily calculated. With the current efficiency established the daily caustic production of a cell is easily calculated.

Under most conditions a brine feed rate set to give 52% conversion of the salt produces the most economical operation in the Hooker cells. With 52% of the feed salt converted the effluent or cell liquor contains 1350 lb. of NaCl/M lb. of caustic soda produced which is usually called the salt-caustic ratio. The recommended Hooker practice is to saturate the brine at about 60° C. and heat the saturated brine feed to about 75° C. Commercially, that results in an average cell feed of brine containing 324 g./l. of NaCl with a specific gravity of 1.210 at 20/15½° C. Since the chlorine and hydrogen leave the cell saturated with water vapor the water removed at the cell and resultant water in the cell liquor are easily calculated a pound of caustic soda. Assuming evaporation to 50% NaOH requires the evaporation of all water in the cell liquor except the one pound that remains with the caustic soda.

Determination of the number of cells required for each plant size and current used is easily determined from the production per cell as given in Table 1 and the plant size. Considering current leakage to ground and operator safety with respect to voltages to ground a circuit of about 200 cells is considered to be the desirable maximum. In practice, that figure may be varied within reason, but for these calculations the figure was made mandatory. To calculate the power requirements, mechanical rectifiers are assumed because they have a uniform conversion efficiency of about 97% for installations as low as about 300 v. which drops off to about 96% at 200 v. The cells in each circuit multiplied by the voltage drop a cell plus 5 v. give the circuit voltage. The circuit voltage multiplied by the circuit current and divided by the conversion efficiency gives the a.c. power required.

The buildings required to house the

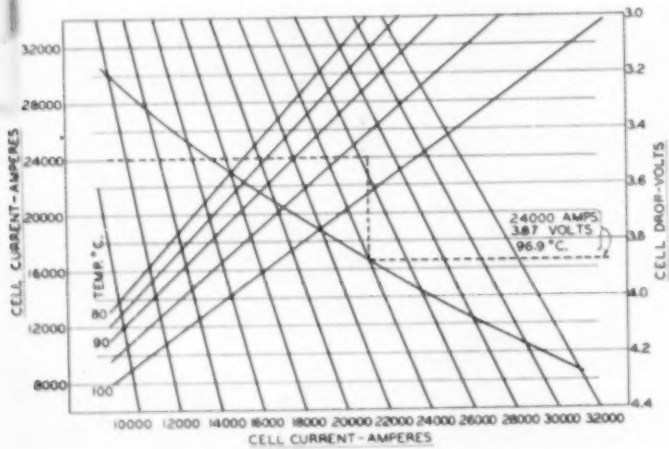

Fig. 4. Type S-3 Cell Characteristics

cells, rectifiers and cell renewal equipment and working space are dependent on the type of cell used and its operating current. The Hooker cells are usually placed in double rows with the cells back to back and spaced far enough apart to provide a service aisle for inspection and piping. The most convenient layout is with two double rows of cells resulting in an economical building width and span for cranes. Space for cell renewal is usually the same width as the cell building by 50 ft. long for small installations up to 180 ft. long, or the equivalent floor area, for a 900-cell installation. Space for rectifiers taken at the cell building width by 36 ft. long for each circuit provides sufficient space for rectifiers, exclusive of transformers. To insure good ventilation a building height of 20 ft. is assumed, although less height can be used.

From the above figures, the capital costs of Table 2 are calculated. Buildings are assumed at $0.50/cu.ft. and rectifiers at $60/kw. installed.

Operating Costs. Variable operating costs are power, steam, cell room operators, cell renewal, miscellaneous and depreciation. For convenience all costs are calculated on the basis of one ton of caustic soda produced at the cell. Since power cost is the major individual item it is calculated at the three rates of 3 mills, 5 mills and 7 mills/kw.hr. using the installed a.c. power required at a uniform rate.

While steam has less effect on the result it is calculated at $0.40, $0.60 and $0.80/M lb. For triple-effect evaporation 0.483 lb. of steam is used/lb. of water evaporated. For double-effect evaporation 0.705 lb. of steam is used/lb. of water evaporated. While the choice of double- or triple-effect evaporation could have an effect on the selection of the cells and the operating current, double-effect evaporation would normally be used only on the 25-ton plant size and possibly on the 50-ton size. While double-effect evaporation should be considered for a contemplated plant, including it in the calculations for this paper would add more work and complications than the results justify.

A determination of the number of cell room operators for a given plant or type of cell is a variable that is actually determined by local plant conditions. For the purpose of this study it is assumed that one operator can handle up to 200 cells, or if there is more than one circuit one operator is required for each circuit. A figure of $1.75/hr., or $42/24 hr./operator is assumed.

Cell renewal includes replacement of graphite, concrete parts, diaphragms, and the labor required for assembly and change in the cell room. Since circuits of Hooker cells operate continuously

TABLE I. BASIC DATA

	TYPE S CELLS					
Cell Current	6000	8000	10,000	12,000	14,000	16,000
Current Efficiency %	94.7	96.0	96.8	97.3	97.7	98.
Tons NaOH/Cell/Day	.2235	.302	.381	.459	.537	.616
Average Cell Voltage	3.26	3.48	3.72	3.94	4.14	4.35
Average Cell Temp °C	80	87	92	95	97.5	99
Lbs Cll Liquor/lb NaOH	9.30	9.12	8.90	8.67	8.42	8.20
Lbs H_2O Evap/lb NaOH to 50%	5.95	5.77	5.55	5.32	5.07	4.85

	TYPE S-3 CELLS					
Cell Current	12,000	16,000	20,000	24,000	28,000	32,000
Current Efficiency %	94.7	96.0	96.8	97.3	97.7	98.0
Tons NaOH/Cell/Day	.447	.604	.762	.918	1.074	1.232
Average Cell Voltage	3.20	3.43	3.65	3.87	4.08	4.27
Average Cell Temp °C	86	91	95	96.9	98.6	100.0
Lbs Cell Liquor/lb NaOH	9.15	8.95	8.65	8.50	8.30	8.07
Lbs H_2O Evap/lb NaOH to 50%	5.80	5.60	5.30	5.15	4.95	4.72

TABLE 2. CAPITAL INVESTMENTS TYPE S CELLS*

Current	6,000	8,000	10,000	12,000	14,000	16,000
25 Ton Plant Total	$1,427,000	$1,410,600	$380,400	$361,700	$354,400	346,600
50 Ton Plant Total	924,000	762,800	699,000	646,000	625,000	621,500
75 Ton Plant Total	1,341,000	1,150,000	1,013,000	954,000	916,500	898,500
100 Ton Plant Total	1,780,000	1,485,000	1,353,000	1,286,000	1,213,000	1,189,000
150 Ton Plant Total	2,643,000	2,229,000	1,991,000	1,881,000	1,799,000	1,761,000
200 Ton Plant Total	3,491,000	2,926,000	2,651,000	2,492,000	2,399,000	2,312,000

CAPITAL INVESTMENTS TYPE S-3 CELLS*

Current	12,000	16,000	20,000	24,000	28,000	32,000
25 Ton Plant Total	$417,800	380,800	$353,700	$336,900	$329,800	$327,300
50 Ton Plant Total	$ 772,000	669,600	624,000	603,000	590,400	586,100
75 Ton Plant Total	1,128,500	967,700	897,000	855,000	838,700	826,000
100 Ton Plant Total	1,488,000	1,269,500	1,181,300	1,129,300	1,091,500	1,073,100
150 Ton Plant Total	2,188,000	1,909,000	1,734,000	1,645,100	1,604,500	1,588,600
200 Ton Plant Total	2,938,000	2,515,000	2,313,000	2,224,000	2,114,500	2,084,500

* Capital investments do not include brine handling and purification equipment, caustic evaporation, chlorine cooling, drying, compression and liquefaction equipment.

with each cell out of service about 3 hr. two or three times a year no adjustment is required for down time on the cells or circuits. All cell-renewal work is scheduled in accordance with graphite or anode life. Graphite consumption is directly proportional to oxygen formation at the anode which in turn is directly proportional to the loss in current efficiency. Since the loss in efficiency is inversely proportional to the operating current and the loss of graphite is directly proportional to the loss in current efficiency, the graphite life is constant regardless of the operating current. That relation, of course, depends upon proper operation with respect to all the variables that affect current efficiency. It is virtually impossible to control exactly all the variables, but the ideal can be approached and operation maintained close to it; therefore, it is proper to assume ideal operation in determining graphite life, which is taken at 450 days for either type of cell.

Studies have shown that three diaphragms an anode run are the most economical, all factors being considered. While the life of the first diaphragm is shortened by materials from the anode that tend to coat it, the life of the last diaphragm is correspondingly lengthened. However, that does not change average long-term costs.

One plant may have efficient workmen, ideal operating conditions and be liberal with supplies and equipment issued to their men, but, because the cell output is delivered to another process and must match its requirements, that plant may be forced into high renewal costs. Another plant may have ideal conditions for all factors and have exceptionally low renewal costs. However, it is the over-all economic picture rather than the individual items that control, if each item of cost is held to a minimum with respect to the over-all plant economy. Likewise, in a study such as this, individual figures have their effect in the final result. Therefore, to develop a complete picture, reasonable renewal costs were developed and included in the calculations.

For depreciation the cells, piping and renewal equipment were assumed at 15 years' life while buildings and rectifiers were assumed at 25 years' life, using straight line depreciations.

Operating costs from the above are simply worked out a ton of production or a year for each operating condition and steam and power cost. A tabulation of those figures gives the relative operating costs of the various plants with respect to the power load at which they are operated. With the two types of cells and other variables the necessary figures multiply to a point well beyond the reasonable limit to be included for publication. However, business is interested in the profits made from a given investment usually expressed as the per cent return a year on the investment.

To avoid the inclusion of unnecessary figures all costs that would be uniform a unit of production in each of the plants are not included as mentioned earlier. Profit is, of course, the difference between sales price and operating cost. However, since the cost figures used do not by any means represent the total cost to produce marketable products, but only the variable portion thereof, market price quotations have no significance in these calculations. Therefore, an arbitrary figure of $30/ton of caustic soda is assumed in place of a sales price to obtain a figure which is convenient to use and produces positive returns on the investment in all cases except one. The difference between $30 and the cost per ton multiplied by the tons per year divided by the capital cost gives return on the investment which is expressed as a percentage in Table 3.

TABLE 3. RETURN ON THE INVESTMENT % RETURN PER YEAR

Electric Power	TYPE S CELLS 6,000	8,000	10,000	12,000	14,000	16,000	TYPE S-3 CELLS 12,000	16,000	20,000	24,000	28,000	32,000
25 Ton Plant												
$.02/1000												
$.005/kwh	22.95	29.95	32.80	35.80	36.00	36.70	28.65	33.65	37.35	39.70	40.70	40.50
.005	16.53	19.00	21.00	22.10	21.80	21.30	19.02	18.37	16.10	15.80	15.10	14.25
.007	4.85	6.86	9.00	9.01	7.62	6.05	6.97	11.04	11.85	10.80	9.54	7.50
$.40/1000												
.005	29.70	36.80	39.30	38.70	33.30	34.00	29.60	31.05	34.70	37.00	38.05	38.00
.005	12.31	14.59	16.55	17.50	16.05	14.85	15.95	19.75	21.60	22.50	22.50	22.60
.007	1.60	2.60	4.70	6.46	5.08	3.56	4.25	8.14	8.80	8.05	6.87	5.93
$.80/1000												
.005	18.50	24.40	27.75	30.09	31.10	30.45	23.85	28.55	32.05	34.40	35.45	35.40
.005	10.15	14.18	15.98	17.60	16.57	15.10	14.16	17.20	18.78	19.90	20.87	20.90
.007	1.76	3.96	6.13	5.88	6.46	-	4.47	5.96	5.55	5.43	4.85	4.28
50 Ton Plant												
$.02/1000												
.005	25.45	26.50	29.05	29.30	26.40	26.80	23.95	23.98	26.10	28.00	28.75	29.30
.005	14.75	15.05	18.20	18.70	19.60	17.80	15.75	19.35	21.90	22.05	21.70	20.90
.007	0.05	12.10	13.50	14.04	13.09	10.73	13.50	16.97	17.60	16.30	12.60	6.48
$.40/1000												
.005	27.15	31.70	34.25	40.30	42.50	42.10	30.60	39.25	43.10	44.95	45.00	46.28
.005	16.63	20.67	23.40	25.70	26.70	25.00	21.10	26.64	28.90	29.00	28.80	28.20
.007	5.75	9.67	12.60	14.12	13.01	7.98	10.35	14.18	15.00	13.85	11.81	10.30
$.80/1000												
.005	20.90	29.00	32.30	37.40	39.40	37.75	28.65	36.00	40.35	42.00	42.80	43.45
.005	14.18	18.00	21.57	22.95	25.00	24.75	20.00	25.50	27.50	28.25	27.82	27.40
.007	5.60	7.02	7.75	8.82	7.90	5.70	8.21	11.00	11.65	10.32	8.89	7.50
75 Ton Plant												
$.02/1000												
.005	26.00	33.75	41.10	44.50	47.25	47.30	35.65	44.45	49.55	52.45	53.55	54.30
.005	17.20	22.80	28.80	30.80	31.20	31.10	25.50	31.81	34.75	36.05	36.00	35.85
.007	6.37	11.72	15.00	15.15	15.04	13.60	14.80	20.00	20.05	19.70	18.40	17.20
$.40/1000												
.005	27.40	34.80	38.65	41.40	44.30	45.60	38.80	42.80	46.80	48.50	49.50	51.30
.005	14.84	19.50	23.34	27.05	28.20	28.80	21.80	28.80	31.60	32.85	32.90	32.80
.007	6.00	8.90	12.10	12.10	12.35	11.00	11.35	15.70	16.74	16.50	15.30	14.15
$.80/1000												
.005	21.50	25.80	35.55	38.90	41.10	42.55	30.15	38.40	42.25	45.59	47.10	48.50
.005	12.50	17.85	22.10	24.10	25.50	25.37	19.85	25.75	28.15	29.70	29.80	29.80
.007	5.60	6.35	9.17	9.20	9.25	8.20	9.42	12.80	13.05	13.57	12.17	11.17
100 Ton Plant												
$.02/1000												
.005/kwh	23.80	33.10	40.60	44.40	48.00	49.25	34.25	46.00	50.70	53.55	55.50	56.80
.005	16.85	24.05	27.10	30.00	31.90	32.00	23.65	32.60	35.80	37.25	37.65	37.60
.007	8.50	12.70	16.25	15.30	15.75	14.70	13.07	16.90	20.30	20.75	19.70	18.45
$.40/1000												
.005	27.50	32.60	37.70	41.80	46.10	46.00	30.80	42.90	47.50	50.30	52.30	53.30
.005	14.17	21.30	24.60	27.30	28.90	29.60	20.40	29.45	32.60	34.00	34.50	34.60
.007	5.61	9.96	11.30	12.60	12.77	11.77	9.60	16.70	17.75	17.45	16.60	15.55
$.80/1000												
.005	21.05	29.80	34.80	38.80	42.50	43.50	28.80	39.80	44.30	47.10	49.10	50.20
.005	07.07	18.97	21.65	24.17	25.00	25.50	18.18	26.40	29.40	30.80	31.00	31.40
.007	5.20	7.02	8.46	9.46	9.05	8.85	7.59	13.46	14.65	14.33	13.40	12.45
150 Ton Plant												
$.02/1000												
.005	26.00	34.50	43.30	46.70	48.50	49.90	37.80	46.25	52.50	56.00	57.50	57.80
.005	19.07	27.40	28.98	30.80	32.35	33.10	26.50	32.30	37.65	39.10	39.70	38.50
.007	7.88	12.37	16.70	15.60	15.70	14.65	15.74	19.25	22.25	22.50	21.10	19.60
$.40/1000												
.005	25.60	34.70	38.50	42.80	46.50	47.00	34.65	42.80	49.10	52.60	54.10	54.60
.005	14.55	20.74	25.15	27.75	29.10	29.25	22.80	29.15	34.00	36.80	36.00	35.60
.007	5.68	9.70	11.80	12.68	12.68	12.65	11.98	16.30	19.00	19.35	17.85	16.25
$.80/1000												
.005	21.20	29.30	35.50	39.75	42.90	44.00	31.50	39.10	46.00	49.10	49.10	51.80
.005	12.80	18.10	22.15	24.80	26.15	26.55	20.80	26.30	30.80	32.60	32.80	32.30
.007	5.12	7.06	8.81	9.70	9.72	8.74	12.12	13.05	15.15	15.96	14.60	13.15
200 Ton Plant												
$.02/1000												
.005	26.90	36.20	46.45	48.50	48.45	51.60	36.60	46.80	52.00	54.30	58.50	59.50
.005	17.70	25.65	27.05	30.90	32.35	33.00	25.65	29.80	33.70	37.80	40.20	40.00
.007	6.50	13.17	13.05	15.40	15.98	15.20	15.27	19.75	21.80	21.05	20.00	18.75
$.40/1000												
.005	24.40	33.05	39.20	42.40	46.40	47.40	32.90	43.10	48.75	51.00	53.10	54.10
.005	15.26	21.85	25.70	27.60	29.30	28.80	22.10	29.85	33.65	34.65	36.00	36.00
.007	5.65	9.87	12.50	12.40	12.88	12.20	11.52	16.60	18.95	18.38	18.70	17.25
$.80/1000												
.005	22.00	30.50	36.20	39.60	42.70	44.70	30.85	39.95	46.60	47.90	50.00	53.00
.005	12.88	19.07	22.75	24.55	26.20	27.10	20.65	26.70	30.40	33.20	33.70	33.60
.007	5.68	7.60	9.25	9.60	9.98	9.50	9.50	13.50	15.55	16.55	15.60	14.30

Note: Since only part of the cost figures and an assumed sale price are used, as explained in the text, the above returns on the investment are comparative rather than true returns.

Conclusions

Figure 5 is a plot of the returns on the investments for the 50-ton plant at $0.40 steam showing the effect of variable power costs and type of cell used. Obviously, the Type *S*-3 cells produce the higher return on the investment under most of the conditions. The optimum operating point would be that condition which produces the highest return. Thus, with 7-mill power the peaks are 12,000 amp. for the Type *S* cell and 20,000 amp. for the Type *S*-3 cells. As the unit power cost decreases the return on the investment increases and the peaks in the curves move towards higher operating currents. That indicates optimum operation for 5-mill power at 14,000 and 24,000 amp. respectively for each type of cell and 15,000 to something more than 32,000 amp. for 3-mill power. However, it is furthermore noted in Figure 5

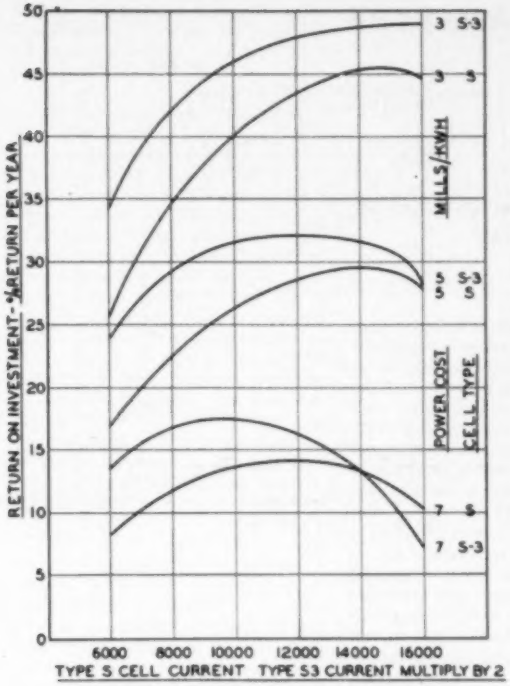

Fig. 5. Return on Investment 50-Ton Plant

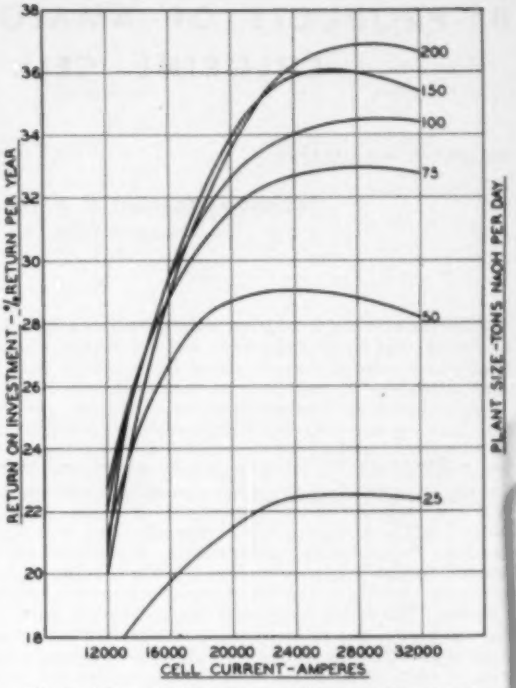

Fig. 6. Effect of Plant Size on Return of Investment

that the curves are relatively flat. Since some of the optimum currents are well above the safe operating limits as indicated by the current-carrying capacity of the leads that is fortunate. Otherwise, there would be too much temptation to overload the equipment without considering the cost of burning out connections between cells. It is true that the copper could be increased, but so would the capital cost and difficulty of making good connections so there would be little, if any, gain.

Figure 6, a plot of the return on the investment against operating current for the various plant sizes for the Type *S*-3 cells with steam at $0.60 and power at 5 mills, is typical of the plots that can be made for other cost conditions. It is interesting to note that as the plant sizes increase, the difference in returns tends to become less. That is to be expected. With a small plant the fixed cost of renewal equipment and excess labor costs are a more prominent portion of the total than in the larger plants. Thus as a critical size is reached with a given size cell, further increase becomes a straight multiple of the previous size with virtually constant returns on the investment.

That is more evident in Figure 7 which plots the return on the investment against plant size at the optimum operating current for each of the two sizes of cells with power at 5 mills and steam at $0.60/M lb. The Type *S* cell has reached its maximum with a plant of about 110-ton capacity and remains constant, while the Type *S*-3 cell is rapidly approaching that point at 200-ton capacity.

Figure 7 indicates another interesting point in the smaller plants, namely that even at 25 tons the Type *S*-3 cell still gives a higher return on the investment. However, if figures are developed using mercury-arc rectifiers, rotary converters, or motor generator sets, the conversion efficiencies would drop off rapidly as the cell circuits become shorter. That would force the larger cells in small plants to use less efficient conversion equipment to meet the voltage requirements resulting in lower returns for the larger cells. Previous work has indicated that if mechanical rectifiers are not considered the curves for the two cells would cross at a plant size of about 50-ton capacity.

In general, as plant size is increased the size of the cell used should also increase. Furthermore, with the high capital costs involved cells should be operated at the maximum current consistent with their design.

Acknowledgment

The author wishes to express his appreciation to the management of the Hooker Electrochemical Co. for permission to make public the results of this study and to the various personnel of the compay whose data and reports have assisted in the proper correlation of cell characteristics and particularly to M. S. Kircher of the Hooker Electrochemical Co. for his helpful suggestions.

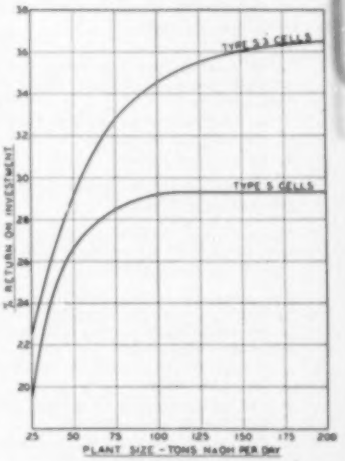

Fig. 7. Comparison—Type S and Type S-3 Cells

BY-PRODUCTS OF AMALGAM-TYPE CHLORINE CELL

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Utilization of metal amalgams in the preparation of industrially important chemicals, and in the separation and purification of metals is a comparatively new science. In this paper the technical basis for the formation and utilization of amalgams is discussed. Processes are described for the production of free metals such as sodium, potassium, lithium, zinc and lead by two different techniques—(a) distillation of mercury from the amalgam, and (b) electrodeposition. Caustic alkalies are produced by decomposition of alkali amalgams with water, and metal alcoholates by decomposition of the amalgam with a suitable anhydrous alcohol. Various metallic salts are produced by direct union of the metal dissolved in the amalgam with other elements and acidic compounds to produce, for example, sodium sulfide, sodium hydrosulfite, sodium chlorite and sodium nitrite. Amalgams are useful for organic reductions, and processes are described for the production of azobenzene and hydrazo toluene. The latter compound can be further used in a cyclic process for the production of hydrogen peroxide. Additional applications in the field of amalgam metallurgy include phase-exchange reactions and reduction of metallic chlorides with sodium amalgam to produce such metals as titanium and zirconium.

IN the amalgam process for the production of chlorine an aqueous solution of a chloride salt is electrolyzed. Chlorine gas is evolved at graphite anodes, and the metal of the salt in question is deposited on a flowing mercury cathode. The free metal dissolves in the mercury to form an amalgam, which is withdrawn from the electrolysis compartment. This amalgam may be utilized in a number of ways, which can be classified as follows:

1. For the production of free metals: for example, sodium, potassium, lithium, zinc, lead, etc.
   a. By distillation of mercury from the amalgam, leaving free metal
   b. By electrodeposition
2. Production of caustic alkalies by decomposition with water
3. Production of metal alcoholates by decomposition of the amalgam with a suitable anhydrous alcohol
4. Production of various metallic salts by direct union of the metal dissolved in the amalgam with other elements and acidic compounds:
   a. Sodium sulfite by reaction of sodium with sulfur
   b. Sodium hydrosulfite by reaction of sodium with sulfur dioxide
   c. Sodium chlorite by reaction of sodium with chlorine dioxide
   d. Sodium nitrite by reaction of sodium with nitrogen peroxide
5. For organic reductions:
   a. Nitro to azo to hydrazo (aromatics)
   b. Quinone to hydroquinone
   c. Oxalic acid to glyoxylic acid
   d. Ketones to pinacones
6. Amalgam metallurgy:
   a. Separation of various metals in their pure form from their mixed electrolytes: for example, lead, copper, zinc, from the chlorides
   b. Reduction of metallic chlorides to produce other metals: for example, reduction of titanium and zirconium chlorides to produce titanium and zirconium

The greatest use today of the amalgam-type chlorine cell is for the production of caustic soda. The major portion of the electrolytic chlorine produced in countries outside of the United States is in the amalgam-type cell. In the United States, the diaphragm cell predominates, but the amalgam-type cell is gaining in popularity (*17, 20, 25*). The raw material is sodium chloride, usually in the form of rock salt. Products of electrolysis are chlorine gas and sodium amalgam, usually in a strength ranging between 0.1 and 0.3% Na. In most existing plants, the sodium amalgam is decomposed with water to form caustic soda and hydrogen gas. The caustic so produced is exceptionally pure and can be made in strengths up to 70% NaOH. After stripping the sodium from the amalgam, the mercury is returned to the electrolysis cell. A schematic flow sheet of the mercury-cell process is shown in Figure 1.

There are many varieties of mercury cells (*See* Fig. 2). First, there is the rocking cell invented by Castner, and still in use today at the Niagara Falls plant of the Mathieson Chemical Corp. (*9*). These cells are small, carrying about 1500 amp. and are unsuitable for the manufacture of amalgam by-products. Second, there is the broad class of stationary-type cells with horizontal flowing mercury cathode. In this type of cell, mercury is circulated by means of a pump. Such cells are built in a wide range of sizes, from the 1500-amp. Sörensen cell to the 30,000-amp., 14-meter cell of the I. G. Farbenindustrie (*29*). It is practical to utilize the amalgam produced in such cells, particularly in the larger sizes, for the production of by-products other than caustic alkalies. Third, there is the Honsberg cell with the vertical rotating disc cathodes (*31*). These cells are built in large sizes, existing installations in Germany having a capacity of 28,000 amp. each. Such cells are particularly adapted as amalgam producers for by-product manufacture.

It is beyond the scope of this paper to discuss the relative merits of the various commercial types of mercury cells, or to discuss the details of operation, except insofar as they have a bearing on the utilization of the amalgam for by-product manufacture. In a cell room of any size, many individual cells are required. Assuming a 95% current efficiency, for each thousand cell amperes, 66.5 lb. of chlorine and 43.2 lb. of sodium are produced. Service connections, such as saturated brine feed and depleted brine effluent, chlorine gas, etc., are manifolded to the cells in parallel. On the other hand, the cells are electrically in series, so that each cell has a different operating potential from ground. The two possible ways of using the sodium amalgam are distinguished thus:

a. *Cell Sized Unit.* For example, in the manufacture of caustic alkali, it is customary to attach a decomposition chamber to each cell, thus keeping the mercury potential in each manufacturing unit unchanged.

b. *Group Sized Unit.* For example, if the sodium were to be recovered from the amalgam by distillation, as in the Moulton process (vide infra), amalgam flowing from the group of cells is combined, and after recovery of the sodium, the mercury fed to the group is manifolded to the individual cells. This necessitates a mechanical break in the amalgam and mercury flows of individual cells in order to insulate them electrically from the combined flows, which would of course be at ground potential.

Sodium in the form of sodium amalgam is cheaper pound for pound than

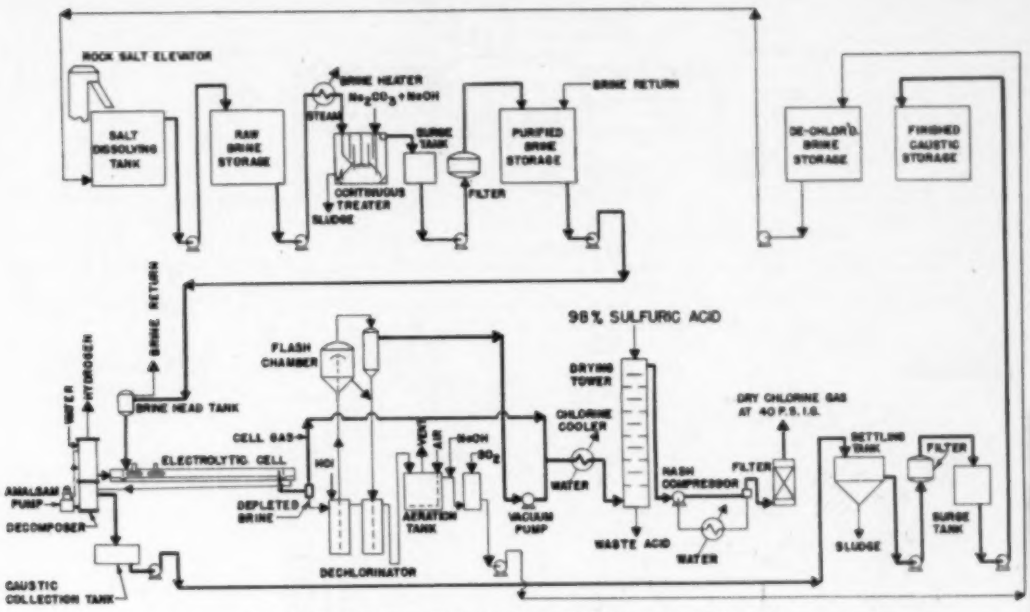


Fig. 1. Typical Flow Sheet Amalgam Cell Process for Chlorine. By-product shown is caustic.

metallic sodium. In the manufacture of chlorine and caustic soda, it is customary to apportion the cost of electrolysis to these two products on a weight basis. Thus the cost of chlorine gas or caustic soda is identical, and usually in the range of $20 to $30/ton. On this basis, a fair valuation of the sodium content in the amalgam would be 40/23 equals 1.74 times the cost of the NaOH, or in round figures, perhaps $35 to $52/ton of Na (1.75 cents to 2.6 cents/lb. of Na). The present market price for metallic sodium is about 18 cents/lb., and the cost of manufacture is probably in the range of 9 cents to 12 cents/lb. Roughly speaking then, sodium as amalgam costs about one fifth as much as metallic sodium. The problem before us resolves itself into two questions: To what extent can the cheaper sodium amalgam be substituted for metallic sodium in the manufacture of industrially important chemicals and to what extent can the cheaper sodium amalgam be used for the manufacture of industrially important chemicals which do not require the use of metallic sodium? Before discussing these questions, some technically important properties of amalgam are considered.

Properties of Amalgam. The solubility of the metals in mercury is given in Table 1 (*15*). The alkali metals—sodium, potassium and lithium, must be classed as having rather low solubilities at ordinary temperatures. When amalgams of these metals are produced by electrolysis of aqueous chlorides, one is limited to a temperature of about 100° C.

TABLE 1.

Solubility of the Metals in Mercury (15)

Class	Metal	Weight %, gms. per 100 gms. Amalgam 15-20°C	70°C
Over 10%	Tl	43.0%	52.0%
1 to 10%	Cd	6.0%	20.0%
	Ce	3.5%	4.0%
	Zn	2.0%	6.0%
	Bi	1.4%	11.0%
	Pb	1.3%	7.0%
	Rb	1.2%	3.5%
0.1% to 1%	Sr	1.0%	1.8%
	Sn	0.6%	4.0%
	Na	0.6%	1.0%
	K	0.4%	1.8%
	Ba	0.3%	0.8%
	Ca	0.3%	0.7%
	Mg	0.3%	0.7%
0.01% to 0.1%	Au	0.1%	
	Ag	0.04%	
	Li	0.04%	
0.001 to 0.01%	Cu	0.003%	
	Mn	0.002%	
	Al	0.001%	
Insoluble	As, Be, Co, Cr, Fe, Ge, Ce, Mo, Ni, Sb, Si, Ta, Ti, U, V, Wo, Zr.		
Unknown Solubility	Ce, Cp, Dy, Er, Eu, Gd, Hf, Ho, In, Ir, La, Nb, Nd, Os, Pa, Pd, Pr, Pt, Ra, Re, Rh, Ru, Sc, Sm, Tb, Th, Tu, Y, Yb		

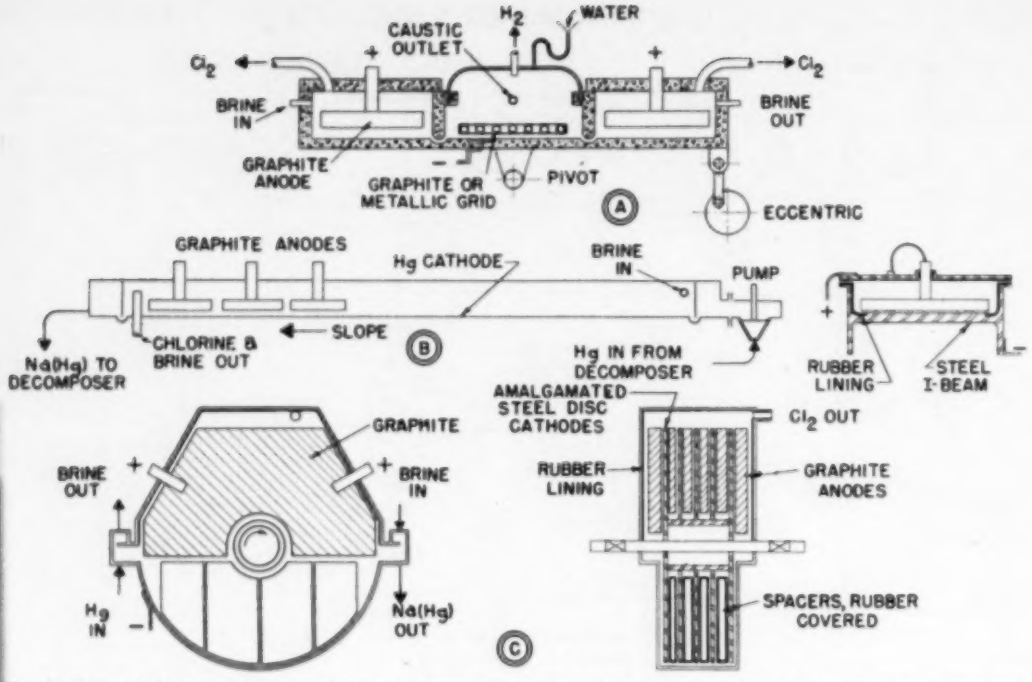


Fig. 2. Types of Amalgam Cells. A. Castner Rocking Cell. B. I.G. Farben Horizontal Cell. C. I.G. Farben Vertical Cell.

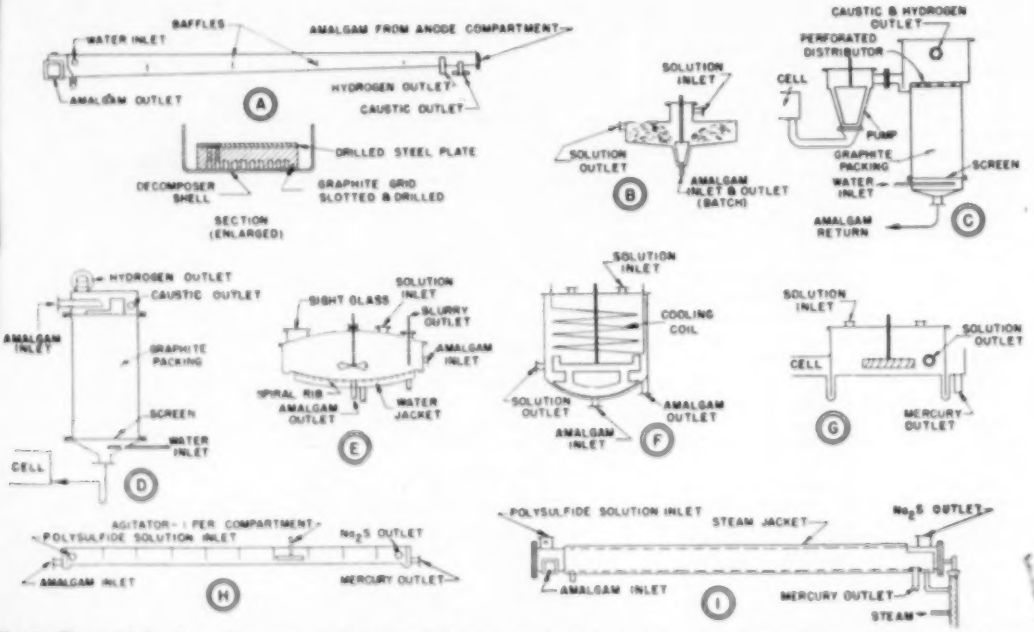


Fig. 3. Types of Amalgam Reactors. A. Horizontal Decomposer for Caustic Alkali. B. Phase Exchanger for Zinc and Lead Amalgams. C. Tower Decomposer Mercury Flooded for Caustic Alkali, Alcoholate. D. Tower Decomposer Nonflooded for Caustic Alkali, Sulfide. E. Contactor for Hydrosulfite. F. Contactor for Reduction of Nitrobenzene to Azobenzene. G. Contactor for Reduction of Azo to Hydrazotoluene. H. Compartment Reactor for Sulfide. I. Tubular Reactor for Sulfide.

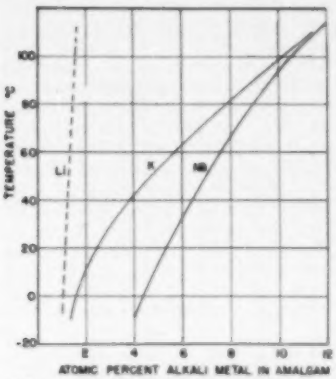


Fig. 4. Solubility of Alkali Metals in Mercury.

maximum. Solubilities of the alkali metals between 0° C. and 100° C. are plotted on an atomic per cent basis in Figure 4.

Amalgams may be further classified into three types as shown in Figure 5 (*15*). These are:

1. *Gallium Type*—Fe, Ni, Co, Mn, Cr, Al, Ga:
   - Amalgamate with difficulty
   - Insoluble in mercury
   - Overvoltage with respect to pure metal
   - No affinity for mercury
   - Especially suited for retort processes
2. *Zinc Type*—Zn, Pb, Cd, Tl, Sn, In, Bi:
   - Easily amalgamated
   - Dissolve readily in mercury
   - Approximately same potential as pure metal
   - Form mixed crystals
   - Especially suited for phase separations and electrolytic separations
3. *Sodium Type*—Na, K, Rb, Cs, Ca, Sr, Ba:
   - React completely rather than superficially
   - Low solubility in mercury
   - Undervoltage with respect to pure metal
   - Form compounds with mercury
   - Can be formed by aqueous electrolysis

The solution pressure of the dissolved metal in the amalgam may be either lower, equal, or higher than the solution pressure of the pure metal itself. The electrolytic potential of the pure unalloyed metal depends only on the concentration of the metal ions in the solution in contact with the metal; whereas the amalgam potential depends both on the concentration in the aqueous and in the mercury phases. An amalgam of definite concentration in contact with an ionic solution of definite concentration, has exactly the same potential as a ten-times more diluted amalgam in contact with a ten-times more diluted solution; or a ten-times more concentrated amalgam in contact with a ten-times more concentrated solution. Amalgam potential can be defined as a constant in a system in which the activity in mercury is exactly equal to the activity in water. This potential can be readily determined by polarography as the so-called half-wave potential.

In Table 2 are shown the standard electrode potentials of pure metal and amalgam in volts, referred to the normal calomel electrode, for several metals of the three types already mentioned. Thus, for iron, nickel and chromium, which belong to the gallium type, the solution pressure is actually greater when dissolved in the amalgam than as a free metal. Therefore, it can be said that amalgamation renders these metals less noble. For zinc, lead and tin, belonging to the zinc type, the solution pressure is substantially the same for the amalgam as for the free metal. For sodium, potassium, lithium and calcium, which belong to the sodium type, the solution pressure of the amalgam is considerably less than that of the free metal. One may say, therefore, that the alkali and alkaline earth metals are made more noble by amalgamation.

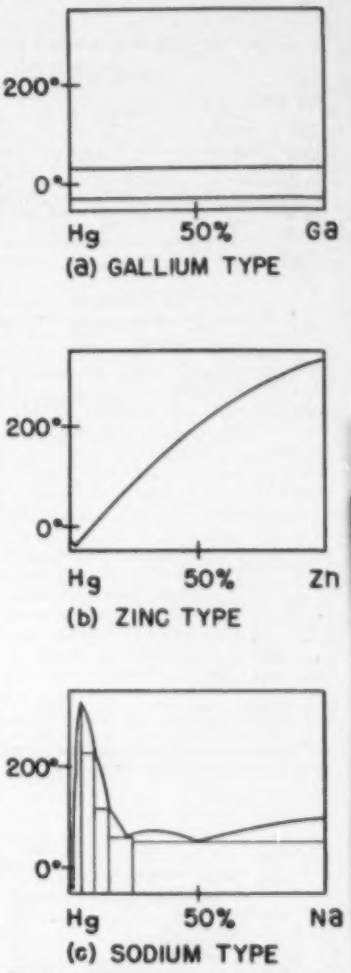


Fig. 5. Amalgam Types After Hohn (*15*)
a. Gallium Type, Fe, Ni, Co, Cr, Al, Ga.
b. Zinc Type, Zn, Pb, Cd, Tl, Sn, In, Bi.
c. Sodium Type, Na, K, Rb, Cs, Ca, Sr, Ba.

TABLE 2.

Standard Electrolytic Potentials and Half Wave Potentials Referred to Normal Calomel Electrode, Volts.

Type	Metal (5)	Amalgam (15)	Difference
Gallium Type			
Fe	-0.721	-1.33	+0.61
Ni	-0.511	-1.08	+0.57
Cr	-0.83	-1.42	+0.58
Zinc Type			
Zn	-1.038	-1.06	+0.02
Pb	-0.406	-0.46	+0.05
Sn	-0.421	-0.47	+0.05
Cu	-0.064	-0.03	-0.03
Sodium Type			
Na	-2.994	-2.15	-0.85
K	-3.205	-2.17	-1.04
Li	-3.240	-2.30	-0.94
Ca	-3.043	-2.22	-0.82

This property of undervoltage of the alkali metal amalgams is important. For many of the reactions discussed here, use of the free alkali metal would be technically difficult, or impossible, to say nothing of the great expense. Sodium metal, for example, reacts violently with water, but sodium amalgam reacts hardly at all, excepting under special and controlled conditions. The overvoltage

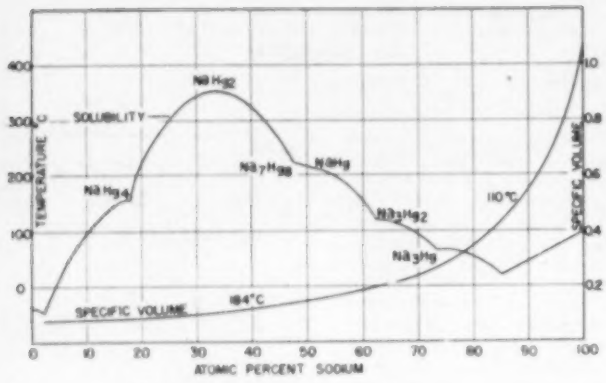


Fig. 6. The System Sodium—Mercury.

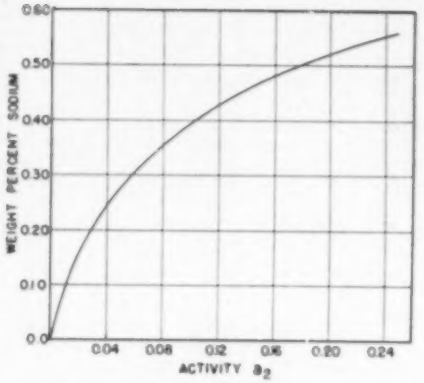


Fig. 7. Activity of Sodium in Sodium-Amalgam Temperature 25° C.

Activity coefficient taken as unity at infinite dilution.

of hydrogen gas against amalgam is high. Thus it is possible to bring about a controlled reaction between sodium amalgam and various other reactive compounds *in aqueous solution*, with high efficiency and little loss due to attack of the sodium on the water to form hydrogen.

It is interesting to note that:

"formation of sodium amalgam from aqueous electrolytes is possible only because of a high over-voltage of hydrogen on mercury. The potential between a saturated sodium chloride solution and 0.2% sodium amalgam is —1.82 v. The over-voltage of hydrogen on the amalgam at the current densities generally used in electrolysis is about —1.30 v. The pH of the solution next to the amalgam is probably about 9, so that the equilibrium hydrogen discharge potential would be about —0.61 v., and the potential for hydrogen discharge would be —1.91 v. At the cathode, a reaction with the most positive potential takes place, so that sodium instead of hydrogen is discharged" (9).

The electrolytic potential of a metal in contact with its ion in aqueous solution is given by the equation,

$$E = E_a + \frac{RT}{NF} \ln a \qquad (1)$$

where E_a is the standard electrode potential and a is the activity of the ion in

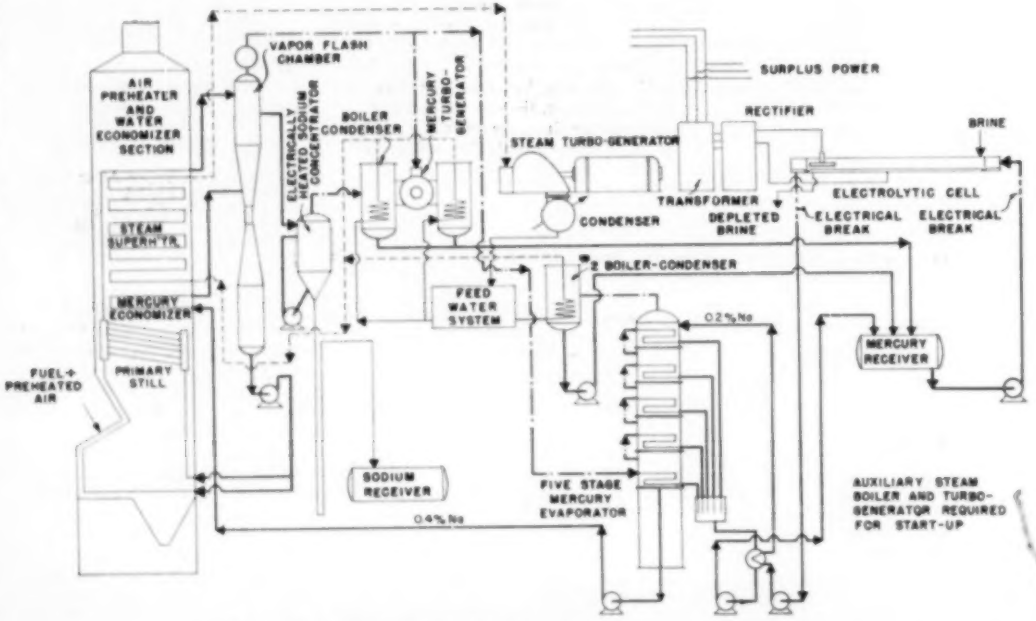


Fig. 8. Moulton Process for Metallic Sodium with Power Generation.

the solution. For accurate results it is necessary to use activities rather than concentrations in the above equation. The activity of an ion equals the product of the activity coefficient and the ion concentration. The activity coefficients of various ions in water have been the subject of much study and values can be found in physicochemical tables. On the other hand, the activity coefficients of amalgam are not so well known. The activity of sodium in sodium amalgam has been calculated from the data of Richards and Conant (*26*), and is shown in Figure 7. In this plot the activity of sodium is taken as zero at infinite dilution.

The potential of the half-cell (*18*)

$$\text{Na(s), Na(amalgam 0.206)};$$

$$E = -0.8452 \text{ v.} \qquad (2)$$

From Figure 7, the activity of a 0.206% amalgam is 0.029. Hence, the potential of the cell

$$\text{Na(s), Na(amalgam } x\%);$$

$$E = -0.8452 + 0.059 \log \left(\frac{a_x}{0.029} \right) \qquad (3)$$

or

$$E = -0.755 + 0.059 \log a_x \qquad (4)$$

Metallic Sodium from Sodium Amalgam by Distillation Technique. It has been proposed to operate a mercury cell at a high enough sodium concentration in the amalgam to permit the recovery of a solid alloy, $NaHg_2$, by cooling the amalgam. Thus, if the temperature of electrolysis were maintained above 70° C., the sodium in the amalgam might be built up to 1.0%, which corresponds to its solubility at 70°. Solubility at zero degrees is about 0.5%. Hence, approximately half the sodium could be recovered by filtering out the solid crystals. The filtrate would then be reheated and recycled to the electrolysis cell. Metallic sodium can be recovered from the $NaHg_2$ by distilling off the mercury in a retort. While this process was the subject of a patent (*7*), it is probable that the process would be impractical. When the sodium concentration in the amalgam is allowed to build up to more than about 0.2 to 0.3% Na, the current efficiency of a mercury cell begins to drop, hydrogen begins to be evolved in dangerous quantities along with the chlorine, and difficulties with "thick" mercury or mercury "butter" are encountered. Therefore this process can be ruled out of practical consideration.

A more practical approach to the problem was made by Seth Moulton (*4, 22*). A schematic flow sheet of the Moulton process is shown in Figure 8 (*23*).

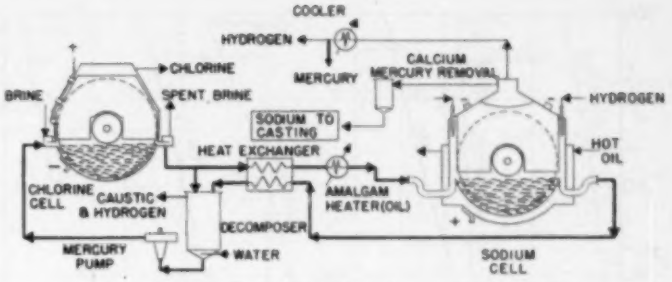


Fig. 9. Electrodeposition of Sodium from Sodium Amalgam. Gilbert process, as carried out by I.G. Farben at Gersthofen.

Moulton proposed to run the mercury cells at the usual strength of 0.2% Na so as to insure good electrolytic operation. He then proposed to concentrate this amalgam to about 0.34% Na in a multiple-effect vacuum evaporator using mercury vapor as a heating medium. The partly concentrated amalgam was then to be concentrated to approximately 50% Na in a mercury boiler of the same general type as used by the General Electric Co. for the generation of power. It will be noted that the melting point of 50% sodium amalgam (90 atomic %) is approximately 42° C. By operating the boiler on a continuous basis, one completely avoids the high melting intermediate amalgams, the maximum of which corresponds to the compound $NaHg_2$ with a melting point of 354° C. The 50% amalgam take-off was then to be further rectified in an electrically heated retort to produce liquid sodium metal.

Perhaps the most interesting feature of the Moulton scheme was the proposed generation of electric power in a G.E.-type mercury steam binary unit (*8, 28*). Mercury vapor was to be expanded in mercury turbines from a temperature of 1150° F. to 438° F. The mercury was to be condensed in a water evaporator to produce steam at 280 lb. pressure, 411° F. The saturated steam was to be superheated to 510° F., and this steam expanded in conventional turbines. The combined mechanical output of the mercury and steam turbines would be sufficient to generate all the electric energy required for the electrolysis and auxiliaries for the entire plant. The estimated fuel consumption was 5.6 tons of coal/ton of sodium metal. The capacity of the mercury steam electric plant was estimated to be 339 kw./ton of sodium, or about 8000/ kw.hr./ton of sodium.

Many technical questions are involved here, and they have been given detailed consideration by Moulton (now deceased) and his associates. It is noteworthy that the boiling-point rise due to the presence of 50% sodium in the mercury is said to be surprisingly small. The density of the 50% amalgam is about one thirteenth that of mercury. Consequently, the amount of mercury tied up in the boiler is considerably less than it would be in a straight mercury boiler; further, the static pressures involved are much lower. What technical difficulties there may be can not be foreseen. The writer has checked the engineering features carefully, and they appear to have a sound basis. The investment required, including the power plant and the electrolytic plant, is of the same order of magnitude as that required for the manufacture of sodium by fused salt electrolysis. The cost of manufacture by the Moulton scheme should be less.

Metallic Sodium from Sodium Amalgam by Electrodeposition. The possibility of recovering sodium from sodium amalgam by electrodeposition was recognized by Dr. Harvey N. Gilbert of the Du Pont Co. as early as 1936. Dr. Gilbert devised an electrolytic cell with a rotating vertical anode, employing a molten bath of a eutectic mixture of NaOH and NaBr as the electrolyte. This apparatus was patented in 1941 (*14*). The German rights to this invention are held by Deutsches Gold und Silber Anstalt (Degussa).

I. G. Farbenindustrie licensed the process from Degussa and undertook the experimental development of the idea. A 1000-amp. cell was built and operated at Gersthofen, and designs for a 16,000-amp. commercial model were on the drafting boards at the close of the war. Details of the I. G. Farben experiments were reported by W. C. Gardiner (*12*). The principle involved is illustrated in Figure 9.

Sodium amalgam is produced by the electrolysis of brine in the usual way in either a horizontal- or vertical-type mercury cell. The amalgam is preheated in a heat exchanger and then flows to the sodium cell which is maintained at a temperature of 230° to 250° C. In the cell a set of rotating steel discs, the lower half of which dip into a pool of amalgam, pick up a film of amalgam and carry it into a pool of molten electrolyte, which floats on the surface of the mercury. A series of stationary nickel plates, also immersed in the electrolyte, are spaced between the rotating discs so as to leave a gap of about 15 mm. A current is then passed in such a way that the rotating discs are anodic and the stationary plates are cathodic. Metallic sodium in the liquid state plates out on the nickel electrodes and floats to the surface of the molten electrolyte.

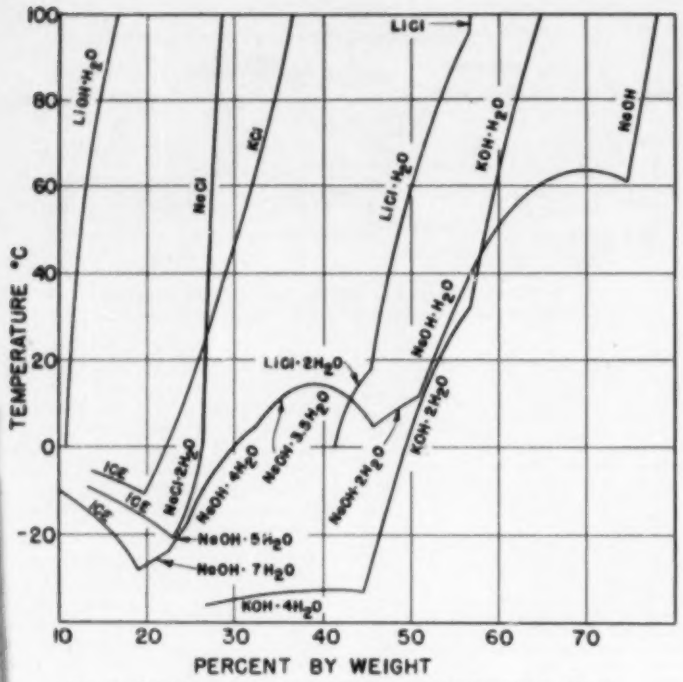


Fig. 10. Solubility of the Alkali Chlorides and Hydroxides in Water.

A suitable electrolyte was found to be a tertiary mixture of 53% NaOH, 28% NaBr, and 19% NaI. Such a mixture is a low melting eutectic and permits operating temperatures as low as 230° C.

The molten sodium is skimmed off the surface of the electrolyte intermittently. To some extent the following reaction also occurs:

$$NaOH + 2Na = Na_2O + NaH \quad (5)$$

The sodium hydride is soluble in metallic sodium, and is removed with it from the cell, and soon decomposes. The sodium oxide forms a mud which is reduced by bubbling hydrogen into the melt through sparger tubes.

It was found that the sodium so produced in this type of cell always contained small amounts of mercury in the range of 0.5% to 1% Hg, depending upon the operating temperature, current density and other factors. This makes the metal hard and unusable for most purposes, and also represents a serious item of expense if not recovered. The mercury was removed by passing the liquid sodium over metallic calcium at a temperature of 380° C. By this means the mercury content was reduced to about 0.01%. The mercury was then recovered from the calcium by retorting.

TABLE 3.

Typical Analysis of Caustic Alkalies Made by the Amalgam Process Percent by Weight

	Caustic Soda		Caustic Potash
NaOH	50.00	KOH	50.0
Na_2CO_3	0.10 - 0.30	K_2CO_3	0.1 - 0.4
NaCl	0.002 - 0.001	NaOH	0.2 - 0.4
Na_2SO_4	0.0004 - 0.0030	KCl	0.01 - 0.02
$NaClO_3$	-	K_2SO_4	0.001 - 0.01
Fe	0.0001 - 0.0006	$KClO_3$	0.001 - 0.005
		Fe_2O_3	0.002 - 0.005

The decomposition potential of the cell is about 0.85 v. (*see* Table 2). In actual practice cell voltages were in the range of 1.5 to 1.9 v.; the current efficiency, 80 to 90%; the d.c. energy required for the recovery of the sodium metal, including the energy lost in the by-pass, averaged 2.75 kw.hr./kg. of Na. The d.c. energy required to produce the sodium amalgam by aqueous electrolysis may be taken as approximately 5.65 kw. hr./kg. Na. The total electrolysis power, therefore, is approximately:

$$5.65/0.80 + 2.75 = 9.85 \text{ kw.hr./kg. of Na} \quad (6)$$

Since the current efficiency in the chlorine cell is less than unity, then if the two cells are in series, part of the current must be shunted through a rheostat in parallel with the sodium cell. In order to keep the chlorine cell in constant operation irrespective of the sodium cell operation, the amalgam may be recycled to the chlorine cell through a conventional decomposer for the production of caustic soda. Thus, along with the metallic sodium, a small amount of caustic soda will be produced.

It is interesting to compare this mercury-cell process with the fused-salt electrolytic process. Degussa operated the Downs cell process, and thereby was in good position to make such a comparison. The Downs cell operates at a temperature of about 585° C.; voltage is about 7.7; current efficency about 78%; d.c. energy for electrolysis is in the range of 13 to 15 kw.hr./kg. Na.

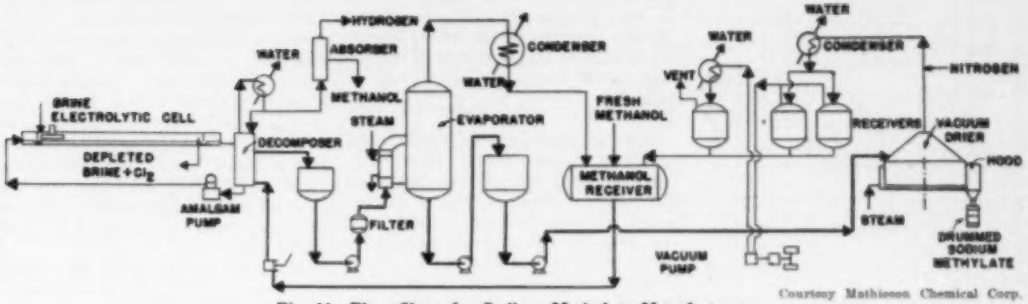
Advantages of Amalgam Process.

1. Lower graphite consumption; 0.97 vs. 1.6 kg./100 kg. Na
2. Lower power consumption; 1000 vs. 1300 kw.hr./100 kg. Na
3. No steam or gas required for salt evaporation and drying
4. More chlorine is simultaneously produced; 188 vs. 154 kg./100 kg. Na

Disadvantages of Amalgam Process

1. Higher salt consumption; 322 vs. 283 kg./100 kg. Na
2. Uses 0.6 kg. calcium/100 kg. Na
3. Uses unknown but probably small amounts of NaBr and NaI
4. Uses mercury, at least 0.06 and probably 0.1 kg./100 kg. Na
5. The product contains 0.01% Hg after purification

A further incentive for using the amalgam process is present for any company which already operates a mercury-cell plant. In such a case, the major portion of the investment has already been made. Sodium cells can be added as required at comparatively low cost, and sodium can be made on a small scale about as cheaply as on a large scale. Cost of the amalgam is determined by the size of the chlorine plant, and is the same no matter whether one cell or all cells are applied to the manufacture of metallic sodium.



Courtesy Mathieson Chemical Corp.

Fig. 11. Flow Sheet for Sodium Methylate Manufacture.

Caustic Alkalies from Alkali Metal Amalgam. Caustic alkalies of commercial importance are the hydroxides of sodium, potassium and lithium. These can be made from the corresponding amalgam by decomposition with water. Most existing amalgam-type chlorine plants produce caustic soda; a few produce caustic potash; and so far as is known, there are no existing plants producing lithia. Decomposition takes place in a denuding compartment where the amalgam acts as an anode, and is short-circuited to a cathode, the electrolyte being a caustic alkali solution. Taking sodium amalgam as the prototype, the reactions are,

Anode:

$$NaHg_x - e = Na^+ + xHg \quad (7)$$

Cathode:

$$H_2O + e = OH^- + \tfrac{1}{2}H_2 \quad (8)$$

Pure water in sufficient quantity is supplied to the decomposer to carry on the above reactions and to carry away the sodium hydroxide formed. The escape of hydrogen also evaporates water from the solution. Solutions containing up to 70% NaOH can be produced directly in the decomposer.

Alkali metal amalgam reacts with water slowly because of the high overvoltage of hydrogen on the amalgam surface. The reaction can be promoted by placing a metal or graphite electrode in contact with the amalgam and the solution. This forms a voltaic battery. The driving force of the cell is the metal amalgam anode potential. Opposing it are the anode polarization, I.R. drop in the caustic solution, hydrogen overvoltage, hydrogen discharge potential, and the I.R. drop of the metallic parts. The amalgam discharge potential depends solely upon the activity of the sodium in the amalgam and the activity of the sodium ion in solution. It is increased by (1) increasing the sodium concentration in the amalgam, (2) decreasing the sodium hydroxide concentration of the electrolyte, and (3) increasing the temperature. The rate of discharge depends upon the amalgam potential and also upon the area of the cathodic surface on which the hydrogen is deposited. In a given cell, therefore, the higher the ampere load, the lower the equilibrium strength of alkali that can be produced.

Amalgam decomposers can be classified, shown in Figure 3, as follows:

a. The sloping, nearly horizontal trough in which the amalgam flows countercurrent to the water. The contact cathodes, usually in the form of plates or slotted blocks of graphite, are laid on the bottom of the trough so that they are in contact with both the amalgam and the water (*30*).

b. The tower type which is filled with carefully sized granules of graphite, over which the amalgam and the water are caused to flow (*13, 31*). Such towers may be operated either flooded or nonflooded with respect to the amalgam, and the flow of water may be either parallel or countercurrent to the amalgam.

Conditions for producing sodium, potassium and lithium hydroxides differ, since they depend on such physical pro-

TABLE 4.

Operating Data on 7-meter I.G. Farben Cells Making Potash & Soda (*32*)

Type of Operation	Potash	Soda
Current Load - amperes	12,000	12,000
Cathodic current density - amps/m^2	2,440	2,440
Anodic current density - amps./m^2	2,660	2,660
Brine concentration in gpl KCl or NaCl:		
Feed	345-350	310
Discharge	270-280	250
Brine flow per cell - L/hr.	400-450	400
Temperatures, °C:		
Brine feed	55-60	60
Brine discharge	80	80
Decomposer liquor	80-90	80
Voltage per cell:		
For new anodes	4.1	4.3
Average	4.3	4.5
Current efficiency percent	92-94	94-96
Hydrogen in chlorine gas, percent	1.5-2.0	1.0-1.5
Anode life in kiloampere hrs. per set	60,000	
Percent K or Na increase in amalgam	0.20	0.15

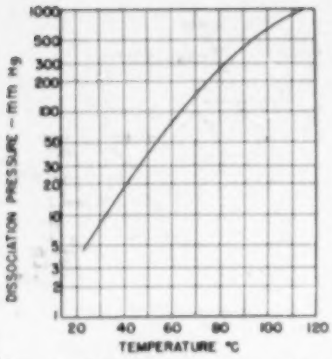


Fig. 12. Dissociation Pressure of the System $NaOCH_3 \cdot CH_3OH \rightleftarrows NaOCH_3 + CH_3OH$

perties as the solubility of the metal in the amalgam (*see* Fig. 4); the solubility of the chloride in the brine used for electrolysis; solubility of the hydroxide in the water used for decomposition (*see* Fig. 10), and the various electrode potentials both in the electrolysis cell and in the decomposer. (*See* Table 2.) At the usual cell operating temperatures, sodium is the most soluble and lithium the least soluble in mercury; therefore the amalgam circulation/1000 amp. is necessarily greatest for lithium and least for sodium. Solubility of the chlorides is greatest for lithium and least for sodium; therefore the brine circulation must necessarily be greatest for sodium chloride. Solubility of the hydroxides is greatest for sodium and least for lithium; at 70°, for example, solubility of NaOH is 75%, and it is practical to operate the decomposer at 70% strength. At the same temperature, solubility of KOH is only 60%, and it would be practical to operate the decomposer at a maximum of about 57%. At the same temperature, the solubility of LiOH is only 13%, and it will be impractical to make caustic lithia at any strength more than about 11%.

The two outstanding advantages of the mercury-cell process for the production of caustic alkalies are: Commercial strength of caustic can be manufactured directly in the decomposer, and does not require further evaporation, and the caustic so produced is exceptionally pure, as seen from the typical analysis in Table 3.

Typical operating data for an I. G. Farben 7-meter cell as operated at Bitterfeld South on potash, and Bitterfeld North on soda, are given in Table 4 (*32*).

In conclusion it may be pointed out that the amalgam-cell process is equally adaptable for the production of high quality caustic soda and caustic potash. No changes in the plant are necessary in shifting from the production of one to the other. For the production of caustic lithia, some adaptations would have to be made.

Metal Alcoholates from Alkali Metal Amalgam. Sodium alcoholates are versatile reagents for organic synthesis. Reactions of sodium methylate, for example, include pyrogenic, metathetic and oxidation-reduction reactions, condensations, and ring closures (*3*). Compounds of commercial importance which may be made by methods involving the use of sodium alcoholates include pharmaceuticals, perfumes, metallic soaps, dyes and organic intermediates. Of particular importance are sulfadiazine and sulfamerazine, the barbiturates, and Vitamin B.

The preparation of the alcoholates has for the most part been accomplished by the usual means of dissolving metallic sodium in the appropriate alcohol, by the simple reaction:

$$2Na + 2ROH \rightarrow 2NaOR + H_2 \quad (9)$$

In practice, however, this procedure is beset with hazards because of the necessity of handling metallic sodium, the violence of the reaction, and the necessity for excluding all trace of free moisture which causes hydrolysis to sodium hydroxide and which adversely affects subsequent yields.

The possibility of producing the sodium alcoholates from sodium amalgam was recognized by the Mathieson Chemical Corp. in the late 1930's, and during World War II a 10,000-amp. amalgam cell was devoted to the production of sodium methylate. The product was isolated as a dry alcohol-free powder, and was packed in airtight containers. The product was actually used in the preparation of sulfa drugs which were critical items in the conduct of the war.

It was found that the lower aliphatic alcohols could be used to decompose sodium amalgam in much the same manner as water is used to produce caustic soda. Reactions take place in decomposers of the type previously described for the preparation of caustic alkali. Hydrogen is evolved from the contact electrode in just the same manner as when water is used for decomposition. In this case, however, it is important that the alcohols be strictly anhydrous; otherwise the alcoholates will hydrolyze according to the reaction:

$$NaOR + H_2O \rightarrow NaOH + ROH \quad (10)$$

Since caustic soda is soluble in the alcohol the product would be contaminated with it, and the product would be less useful for commercial purposes. The reaction of the alcohols with the sodium amalgam is more sluggish than for water. Further, ethyl alcohol reacts more slowly than methyl alcohol, and propyl alcohol reacts too slowly to be practical. Solutions of sodium methylate and methanol can be prepared in the range of 5 to 15% $NaOCH_3$. Data on physical properties of sodium methylate and its solutions are given by Byrkit and Soule (*3*).

A process for producing dry sodium methylate is shown on the schematic flow sheet (Fig. 11). Sodium amalgam from a conventional amalgam cell is contacted with anhydrous methanol in a tower-tpye decomposer to produce a 15% solution. The hydrogen gas evolved is, of course, saturated with methanol, which is recovered partly in a reflux condenser and partly in an absorber. The methylate solution is then filtered and evaporated at atmospheric pressure to a concentration of about 35%, then reduced to dryness on a batchwise basis in a steam-heated dryer. Sodium methylate, $NaOCH_3$, is obtained as a fine white free-flowing powder. It is hygroscopic; it is oxidized slowly by atmospheric air, and will flash like gasoline when the suspended dust is ignited. The dissociation pressure of the methylated sodium methylate is given in Figure 12. The recovered methanol from the evaporator and dryer is recycled to the decomposer; fresh methanol is added equivalent to the alcohol content of the product, plus the process losses.

When one attempts to prepare sodium ethylate in the same manner, there is not only the difficulty of the slower decomposition, but also the following:

a. Since pure ethyl alcohol is involved, the process is subject to all the strict regulations of the Bureau of Internal Revenue.

b. Pure sodium ethylate is not a stable substance, but darkens and undergoes deterioration with age. This can be offset to a considerable extent by the use of organic amine stabilizers

It goes without saying that the potassium alcoholates could be produced in much the same manner as the sodium alcoholates.

Sodium Sulfide from Sodium Amalgam. Sodium sulfide, in strengths up to about 58% Na_2S, can be made by reacting sodium amalgam with a sodium polysulfide solution. The reaction is

$$Na_2S_x + (2x-2)Na(Hg) = xNa_2S + (Hg) \quad (11)$$

A portion of the sodium sulfide produced is used to dissolve up the sulfur

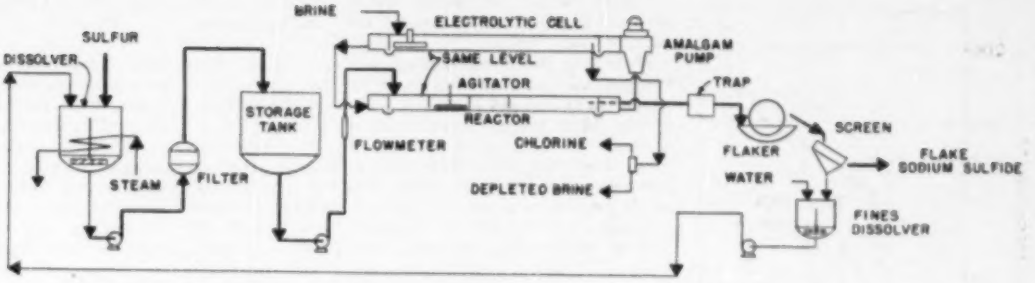


Fig. 13. Flow Sheet for Sodium Sulfide Manufacture Showing Mathieson-Type Reactor.

required to make the sodium polysulfide solution;

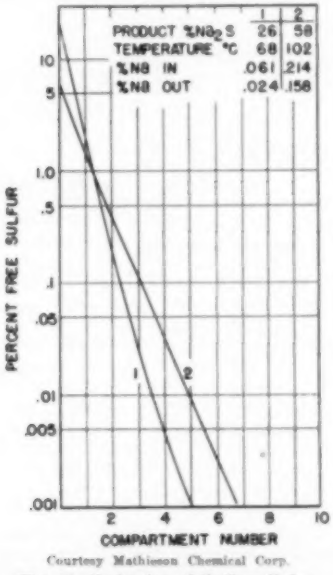
$$Na_2S + (x-1)S = Na_2S_x \qquad (12)$$

The process was developed independently and concurrently in Italy and the United States in the middle 1930's, but patent priority was established by Luigi Achille of Milano, Italy (*1*). United States rights are now held by the Alien Property Custodian. The sodium sulfide amalgam process has been established for some time at Tavazzano, Italy. Patent rights were acquired by I. G. Farbenindustrie and commercial operations were established at Höchst and at Ludwigshafen on a sizeable scale (*29*). The Mathieson Chemical Corp. operated a pilot plant for some time at Niagara Falls.

A schematic flow sheet of the process is shown in Figure 13. Several styles of amalgam reactors or decomposers have been used, as shown in Figure 3. In the Mathieson reactor, the amalgam flows as a flat sheet through a horizontal rubber-lined trough. The trough is divided into a number of compartments and mild agitation for the aqueous layer is provided in each. The flow of the polysulfide is concurrent with the amalgam. The process can be adapted to making crystalline $Na_2S \cdot 9H_2O$, or 55 to 60% flake Na_2S. For the latter, a polysulfide solution corresponding to the formula Na_2S_4 is prepared, and the operating temperature is maintained high enough to prevent freeze-ups. Care must be taken not to strip completely the sodium from the amalgam, otherwise some mercury sulfide will form.

The course of the reaction through the various compartments is shown on Figure 14. It is thus seen that, by compartmentizing, the free sulfur can be reduced to a low value. Sodium sulfide solutions containing 0.01% sulfur or less are practically water white, whereas the polysulfide solution fed to the cell is a deep red.

Reference to the solubility curve (Fig. 15) will make clear why it is impractical to make sodium sulfide in any strength above 60% Na_2S. For the production of sulfide of the highest purity and whitest color, it is essential to exclude air, which otherwise oxidizes the sulfide to thiosulfate, and to avoid contamination with



Courtesy Mathieson Chemical Corp.

Fig. 14. Reduction of Sodium Polysulfide In Compartmentized Reactor.

TABLE 5.

Typical Analyses of Sodium Sulfide Produced by Amalgam Process
(Blanks not reported)

	I.G. Farben (29)		Mathieson	
	30%	60%	30%	60%
Na_2S	30.0	58.0	26.0	51.53
NaHS	-	-	1.06	4.92
Free S	0.06	0.13	0.002	0.002
$Na_2S_2O_3$	-	0.69	1.09	0.10
Na_2SO_3	-	-	0.03	0.09
Na_2CO_3	-	1.48	0.77	1.23
NaOH	-	-	0.00	0.001
Fe	-	0.003	-	0.001
Mg	6 ppm	530 ppm	trace	trace
Total Eq. Na_2S from I_2 titration				58.25

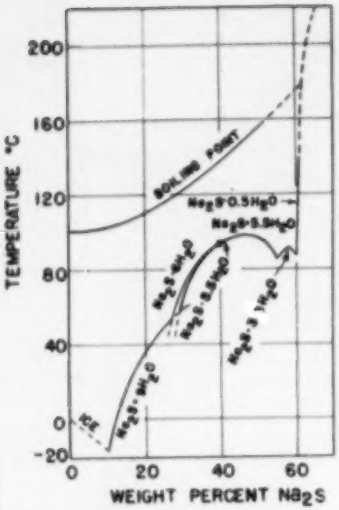


Fig. 15. Equilibrium in the System Na_2S—H_2O

such metals as iron, lead and zinc. The heavy metals in particular give the product a reddish cast.

The decomposer used by the I. G. Farbenindustrie (Fig. 31) is simply a jacketed steel pipe, and the flow of polysulfide and amalgam is concurrent (*29*). While this device has the advantage of simplicity, the reduction is not as complete as in the Mathieson compartmentized reactor. Iron and mercury pick-up is also higher. In Italy, the tower decomposer of the de Nora type is used. The tower is rubber lined and has a ceramic packing. One section is sufficient for making 30% Na_2S but two sections are required for 58% Na_2S (*6*).

Typical analyses of sodium sulfide produced by the amalgam process are given in Table 5.

There is an interesting application of amalgam cells in connection with the production of bleached Kraft pulp. The cooking liquor consists essentially of a solution of sodium sulfide and caustic soda. The black liquor from the digesters is evaporated to about 60% solids and is then used as a fuel for the recovery boilers. The smelt consists essentially of sodium sulfide and sodium carbonate. This is dissolved to form green liquor, and the latter is causticized with lime to form white liquor. Make-up losses of Na_2O and S from the system are supplied by the addition of salt cake to the concentrated black liquor. This salt cake is reduced to sodium sulfide by the carbonaceous matter in the black liquor in the recovery furnace. From a technical standpoint, it would be better to furnish this make-up as sodium sulfide added directly to the white liquor.

In bleaching the brown stock, chlorine gas is used for the first-stage chlorination, and this is followed by an extraction with caustic soda. Later stages of bleaching require calcium hypochlorite which in turn requires chlorine and lime for its preparation. The total chlorine requirements of the process greatly exceed the total caustic soda requirements. If, now, the chlorine is produced in the amalgam-type cell, it is possible to produce the necessary caustic soda in one group of cells and to produce sodium sulfide in the other group of cells. By this means it is possible, in many cases, to balance out the total chlorine and total alkali requirements. The economics of this, of course, depends upon the relative cost of salt cake delivered at the pulp mill, and the cost of sodium sulfide as produced in the amalgam process. In many instances considerable savings could be obtained from the use of the amalgam process.

Sodium Hydrosulfite from Sodium Amalgam. Hydrosulfite is usually made by the reaction between sulfur dioxide and zinc dust. The zinc hydrosulfite thus formed may be used, for example, in the bleaching of groundwood pulp, or it may be converted to sodium hydrosulfite by double decomposition with caustic soda. It is obviously possible to substitute zinc amalgam for zinc metal in the production of zinc hydrosulfite. It is also possible to use sodium amalgam for the production of sodium hydrosulfite directly without going through the intermediate zinc compound. Such a process was operated at Leverkusen, Germany, prior to 1930. A schematic flow sheet is shown in Figure 16 (*2*).

The sulfur dioxide is dissolved in a circulating stream of sodium sulfite so as to maintain the pH of the solution between 5 and 7. The proportion of Na_2SO_3 to $NaHSO_3$ is about 1 to 10. The solution is then contacted with the sodium amalgam in a reactor such as is shown in Figure 3*E*. Good agitation is essential, and the temperature must be maintained at 40° C. maximum. Concentration of hydrosulfite is allowed to build up until crystals of $Na_2S_2O_4 \cdot 2H_2O$ form, and these are removed more or less continuously in a filter press. The dihydrate crystals are then dehydrated by heating rapidly to a temperature of about 60° to 65°, after which they are filtered, washed with alcohol, and dried under vacuum. The reactions are:

$$2\ NaHSO_3 + 2Na(Hg) = Na_2S_2O_4 + 2NaOH + (Hg) \quad (13)$$

$$4\ NaHSO_3 + 2Na(Hg) = Na_2S_2O_4 + 2Na_2SO_3 + 2H_2O + (Hg) \quad (14)$$

$$2\ NaOH + 2NaHSO_3 = 2\ Na_2SO_3 + 2H_2O \quad (15)$$

$$Na_2SO_3 + SO_2 + H_2O = 2\ NaHSO_3 \quad (16)$$

The over-all reaction is simply:

$$2\ SO_2 + 2\ Na(Hg) = Na_2S_2O_4 + (Hg) \quad (17)$$

The final product is slightly contaminated with mercury and may contain up to 0.002% Hg. This fact may render the product useless for photographic purposes, but would not be objectionable

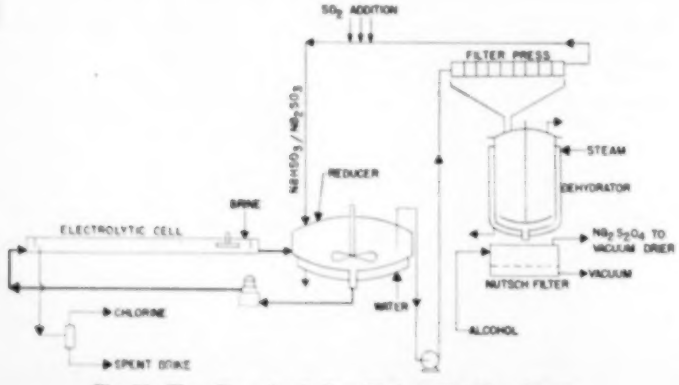


Fig. 16. Flow Sheet for Sodium Hydrosulfite Manufacture.

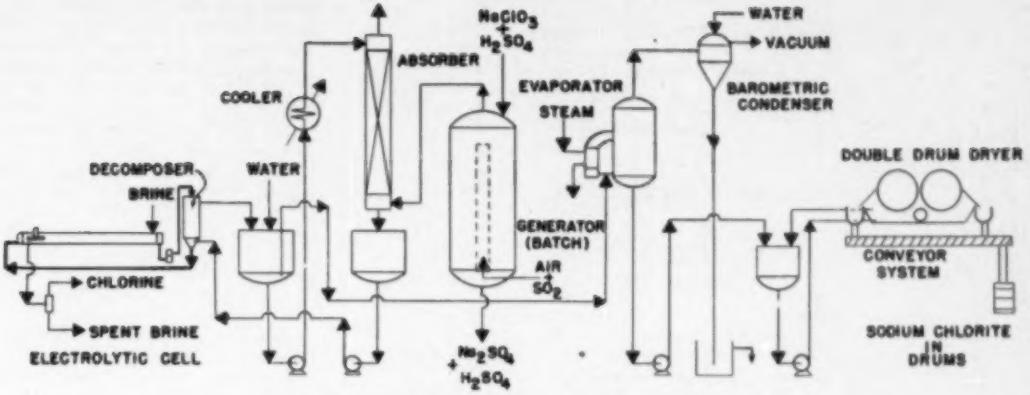


Fig. 17. Flow Sheet for Sodium Chlorite Manufacture.

for use in the reduction of vat dyes or in the bleaching of groundwood pulp. An over-all yield of about 70% is claimed.

It is obvious that zinc hydrosulfite can be produced from zinc amalgam and sulfur dioxide by a similar process (*19*).

Sodium Chlorite from Sodium Amalgam. Sodium chlorite is ordinarily made by the alkaline reduction of chlorine dioxide with such agents as carbon black or zinc dust. A recent patent by Sevón and Sundman (*27*) describes the use of sodium amalgam for this purpose. The reactions are:

$$ClO_2 + Na(Hg) = NaClO_2 + (Hg) \quad (18)$$

$$2\,NaClO_2 + (H_2SO_4) + SO_2 = Na_2SO_4 + (H_2SO_4) + 2\,ClO_2 \quad (19)$$

ClO_2 gas may be generated by the reaction of sulfur dioxide with an acid solution of sodium chlorate in the manner described by Holst (*16*), or by Cunningham (*33*). The ClO_2, diluted with several times its volume of air, is then absorbed in water and contacted with the amalgam at room temperature. Sodium chlorite forms and the solution is recycled through the chlorine dioxide absorber until sufficient strength of sodium chlorite is built up for recovery purposes. The solution must be maintained on the alkaline side; for example, 0.1 normal NaOH. Chlorite is finally recovered by evaporation of the solution. The process is illustrated in Figure 17.

Organic Reductions with Sodium Amalgams. An enormous amount of effort has gone into attempts to use electrolytic methods for organic reductions and oxidations. Most of these attempts may be classified under the heading of reactions at a solid electrode. In nearly all cases such methods require the use of porous diaphragms to separate anolyte and catholyte solutions. In only a few instances have such processes met with commercial success. On the other hand, reductions by means of metallic amalgam have received much less attention. Only in recent years has the polarograph been used to study organic reductions, and even so merely as a tool for analysis. Polarographic studies, however, point the way to a large class of organic reductions that might be carried out by the use of sodium amalgam. A few instances of commercial processes depending upon sodium amalgam will now be discussed. The general reaction for organic reductions with sodium amalgam is as follows:

$$Na(Hg) + H_2O = NaOH + H^* + (Hg) \quad (20)$$

Thus the sodium amalgam in contact with water is a producer of nascent hydrogen, H*. Nascent hydrogen, in a reactive state, is then available for such reductions as the following:

$$H^* + R{:}O = R{\cdot}OH \quad (21)$$

$$8H^* + 2\,R{\cdot}NO_2 = RN{:}NR + 4\,H_2O \quad (22)$$

$$2H^* + RN{:}NR = RNH{\cdot}NHR \quad (23)$$

It must be pointed out that the use of sodium amalgam in this manner does not avoid the production of caustic soda, so that in this sense it is not a complete solution to the problem of making chlorine without caustic soda. The caustic soda produced as a by-product, however, is generally impure, and it is not likely that this would appear as finished caustic for market; on the other hand, it could be used for many purposes by the chlorine producer in his own plant.

Reduction of Nitrobenzene. I. G. Farbenindustrie at Leverkusen (*10*) operated a plant for the reduction of about 3000 kg./day of nitrobenzene to

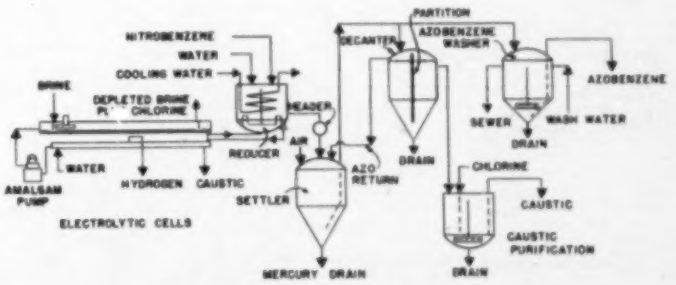


Fig. 18. Flow Sheet for Azobenzene Manufacture.

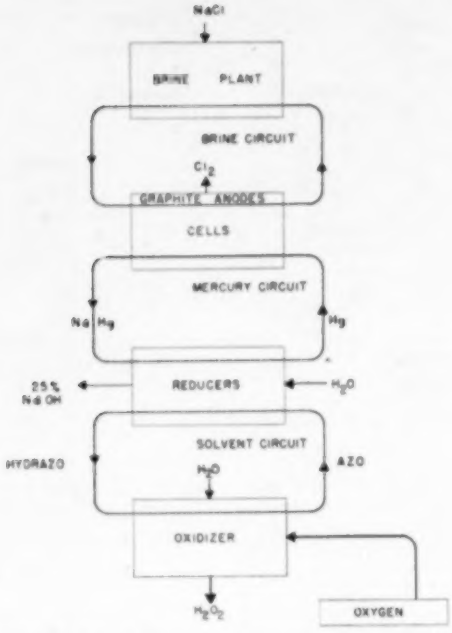


Fig. 19. Principle of Mathieson Process for Hydrogen Peroxide.

azobenzene with sodium amalgam. It was a batch process, carried out in special reactors connected to 30,000 amp. amalgam chlorine cells. The azobenzene was then converted to benzidine by the usual methods. The reaction proceeds according to the equation:

$$2\,C_6H_5NO_2 + 8\,Na(Hg) + 4\,H_2O = C_6H_5\cdot N{:}N\cdot C_6H_5 + 8\,NaOH + (Hg) \quad (24)$$

Azoxybenzene, hydrazobenzene and a small amount of aniline are formed as by-products.

The process is illustrated in flow sheet in Figure 18. Nitrobenzene is reduced in aqueous suspension with sodium amalgam at about 100° C. in a nickel reactor provided with a cooling jacket. The amalgam is supplied by an alkali chlorine cell and the depleted amalgam is recycled to this cell. After the reaction is over, the mixture is run into heated steel tanks where it separates into two layers. The upper layer is azobenzene and the lower layer is an impure caustic solution containing about 50% NaOH. After separation, the azobenzene layer is washed in hot water, and the caustic soda solution is purified with chlorine. The latter is not of standard purity, but can be used for many purposes, for example, in the manufacture of fluorides. The process is alleged to be cheaper than the zinc dust-reduction method, since chlorine and 50% caustic soda are simultaneously produced.

The product of the process analyzes in per cent as follows:

Azobenzene	80
Azoxybenzene	9-10
Hydrazobenzene	7-8
Aniline	2-3

Such a product is suitable for the preparation of benzidine; the only detrimental side reaction is the aniline formation. One trouble inherent in this type of operation is the tendency to form emulsions between organic and aqueous layers. Another trouble is the occasional formation of mercury emulsions and mercury "butter."

Other reductions carried out successfully by I. G. Farben in the same equipment include the reduction of azobenzene to hydrazobenzene (Yield, 82%); of substituted anthraquinone to the hydroquinone; of substituted nitrophenol to the aminophenol; and of substituted diphenylethylene to the diphenylethane.

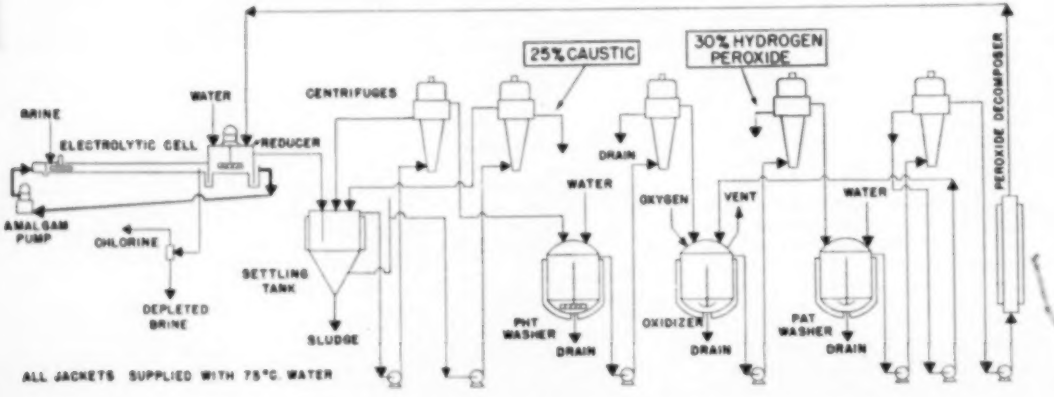


Fig. 20. Flow Sheet for Hydrogen Peroxide.

Production of Hydrogen Peroxide by Para Azotoluene Process. A few years ago the Mathieson Chemical Corp. worked out an ingenious process for the production of hydrogen peroxide (*24*). It makes use of an organic intermediate, which is alternately reduced with sodium amalgam to produce a hydrazo compound and then oxidized with oxygen gas to produce hydrogen peroxide. The principle of the process is illustrated in Figure 19. The organic azo intermediate used is para azotoluene-hydrazotoluene. This is dissolved in a suitable solvent such as ditolylethane. This particular solvent was chosen because of its low volatility, high flash point, complete unreactivity, solvent power for the intermediate, specific gravity such that it can be separated from the caustic soda solution and peroxide solution, and a favorable distribution constant, so that the peroxide formed may be extracted with water to produce concentrated hydrogen peroxide solutions.

The azotoluene is easily produced from nitrotoluene by amalgam reduction, and the ditolylethane solvent may be produced from acetylene and toluene, as described by J. S. Reichert (*34*).

A schematic flow sheet of the process is shown in Figure 20.

This process (known as the Mathieson PAT process) is capable of producing hydrogen peroxide of satisfactory stability in strengths up to about 50% H_2O_2, directly, without distillation. For any chlorine producer having an amalgam-cell type of plant, the additional equipment for producing the peroxide would represent a minor investment. It is alleged that the cost of hydrogen peroxide by this process is much lower, perhaps one half, than the cost by known persulfate processes.

One possible application for the PAT peroxide process is in the bleaching of groundwood pulp for making lighter newsprint. There is potentially a large market for hydrogen peroxide or sodium peroxide for such use, but the present delivered cost of these peroxides has retarded industrial acceptance. For those pulp and paper companies who manufacture sulfite or sulfate pulp in the same general locality as groundwood pulp, it would seem possible to balance the chlorine and alkali requirements for the bleached chemical pulp against the peroxide requirements for the mechanical pulp.

Miscellaneous Reductions. The reduction of quinone and various substituted quinones to the corresponding hydroquinone has already been mentioned. I. G. Farbenindustrie has also conducted experiments on the reduction of oxalic acid to glyoxylic acid with some degree of success. The reduction of ketones such as acetone to pinacone by the use of sodium amalgam is well known. While the foregoing reductions have been demonstrated, so far as can be ascertained, they have never been carried out on a commercial scale. We must recognize, however, that organic reductions with sodium amalgam are potentially an important tool for the synthetic organic chemical manufacturer.

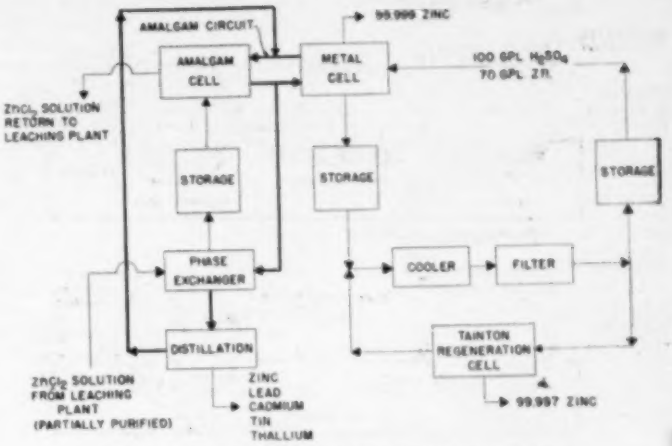


Fig. 21. Flow Sheet for Pure Zinc from Zinc Amalgam.

Amalgam Metallurgy. Amalgam metallurgy may be defined as that branch of metallurgy which makes use of mercury for the separation and winning of metals from mixtures such as occur in the ores, in the concentrates or rejects from hydrometallurgical operations, in the various stages of smelting operations, in electrolyte solutions, or in metal scrap. Methods have been recently worked out in Germany and Austria which appear to be simple, effective and cheap; and which yield metals of a purity heretofore unobtainable by any other means. A comprehensive review of this new amalgam metallurgy was recently written by von H. Hohn (*15*). The physical basis for amalgam metallurgy depends upon the properties of the various metallic amalgams which were discussed earlier in this paper. Some of the practical accomplishments will now be discussed. The new technique is of such wide applicability to metallurgical problems that the writer ventures to predict it will have great industrial importance. The possibility of producing chlorine coincidentally with the metals is a point that is pertinent to the general problems of the imbalance between the markets for chlorine and caustic soda.

Typical equipment developed for amalgam metallurgical purposes is shown schematically in Figures 2C and 3B.

Recovery of Zinc (99.999%) and Chlorine from Leach Solutions of a Chloridized Pyrite Cinder. In Germany, the Duisburger Kupferhütte is in the business of recovering metal values from pyrite cinders collected from German and foreign sulfuric acid plants. The cinders are crushed and then roasted with sodium chloride at 1100 to 1200° C. This forms water-soluble salts of the nonferrous metals and leaves the iron as Fe_2O_3. Gases from the roasting operation are washed with water forming a dilute acid solution containing HCl, H_2SO_3 and H_2SO_4. The roasted cinder is leached with this acid liquor. The leach liquor is treated for recovery of metal values and the remaining iron oxide (purple cinder) is sent to blast furnaces for making pig iron (*11*).

The leach liquor contains the following metals in solution in order of decreasing magnitude: Zn, Na, Mg, Al, Ca, Pb, Cd, Tl, Ni, Ti, Cu, Co, Mn, Sr, Sn, Ba, and Fe. Originally the copper was much higher, but as flotation methods came to be introduced the copper content became poorer and the zinc content richer. It became no longer profitable to recover copper by smelter methods. Further, it was impossible to recover electrolytic zinc by the electrolysis of the neutral chlorine solutions containing so wide a variety of impurities. Therefore Duisburger Kupferhütte had to develop a new method for recovering the values in the raw material, or else go out of business. Thus amalgam metallurgy was born.

It is, of course, necessary to make some preliminary separations in order to prepare a suitable zinc electrolyte. The leach liquor is treated with scrap iron to remove copper. The solution is evaporated and crystallized to remove sodium sulfate. Iron is removed by oxidation with air and precipitation with lime at a pH of 4.5. The filtered solution is next oxidized with chlorine and the pH adjusted to 5.5 with lime for the removal of cobalt and manganese. Finally, the solution is contacted with zinc amalgam for the removal of lead, tin, cadmium and thallium. These latter metals can be recovered from the amalgam in a subsequent process. The final solution contains 120 g./l. NaCl and

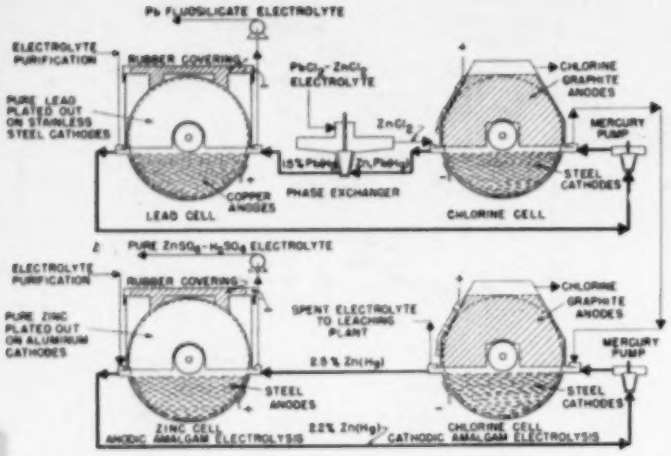


Fig. 22. Electrodeposition of Pure Lead and Pure Zinc from Mixed Electrolyte.

60 to 70 g./l. Zn as $ZnCl_2$ at a pH of about 6. It is electrolyzed in a rotary vertical chlorine cell, of the Honsberg type, to produce a 2¼% zinc amalgam and chlorine gas. Spent electrolyte, still containing about 20 g./l. of Zn, is sent back to the leaching plant. The zinc amalgam then is sent to a metal cell (also a rotary vertical type) in which it forms the anode. The electrolyte used is a solution containing 100 g./l. H_2SO_4 and 80 g./l. Zn. Zinc is deposited from this solution on aluminum cathodes. The zinc is stripped twice a day from the aluminum cathodes, and is said to have a purity of 99.999% Zn. During the stripping operation, the metal cell is short-circuited, but the amalgam cell continues to operate. This causes the electrolyte in the metal cell to build up in zinc concentration and to decrease in sulfuric acid concentration. To restore the original conditions, a portion of the electrolyte is withdrawn and electrolyzed in a Tainton cell which has lead anodes. About five Tainton cells are required for 95 amalgam cells (*see* Fig. 21).

The current efficiencies of the metal cell being higher than that of the amalgam cell, the amalgam-cell current is 24,000 amp., and that of the metal cell, 21,500 amp. Since each amalgam cell is in circuit with one metal cell, it is necessary to dissipate 2500 amp. through a water-cooled rheostat. Only by this means is it possible to maintain the zinc concentration in the amalgam between 2 and 2¼%.

Voltage of the amalgam cell ranges from 2.6 for new anodes, to 3.7 for worn anodes; current efficiency, about 85%; hydrogen in chlorine, 0.2%; graphite life, 1½ years. In the metal cell a current density not more than 1200 amp./sq. meter is used, and the cell voltage is about 0.8 v. Current efficiency is about 95%. Therefore the over-all current efficiency with respect to zinc is 80%, and the over-all voltage for the cell group will average 4 v.

As before stated, the metals more noble than zinc—particularly cadmium, thallium and lead, can also be separated by amalgam metallurgy by a combination of phase exchange and electrolytic methods. In addition to the above, Duisburger is reported to have developed a process for pure manganese, which involves a phase exchange between manganese chloride and sodium amalgam to produce manganese amalgam. The latter is then distilled, leaving manganese of extremely high purity.

Recovery of Spectroscopically Pure Lead, Pure Zinc, Copper Salts, Silver, and Sulfur Chloride from Maubacher Colored Sandstone. Recovery of the various values in such a raw material by conventional methods involving flotation, roasting, smelting, chemical beneficiation, etc., would be difficult indeed. An amalgam metallurgical process has been devised which is a neat solution to the problem (*15*). The methods are too complicated to discuss here, but it is sufficient to say that it involves the use of zinc chloride electrolysis, phase-exchange reactions between zinc and lead amalgams, between lead and copper amalgams, and the electrodeposition of zinc and lead from their respective amalgams. All operations are carried out at low temperatures. A schematic flow sheet showing the separation of lead from zinc is shown in Figure 22.

There are many other applications of amalgam metallurgy, for example, the recovery of pure aluminum from an alloy of aluminum, iron and silicon, such as produced by the reduction of bauxite clay with ferro silicon; and the recovery of aluminum and zinc from scrap. There is also the possibility of preparing alloys in mercury solution, from which they can be recovered by distillation, crystallization, or electrodeposition. Powdered metals suitable for compression molding can also be prepared in some instances. We have given particular emphasis, however, to those processes which involve the simultaneous production of chlorine and metal.

Production of Titanium and Zirconium by Reduction of Chlorides with Amalgam. Production of pure ductile titanium and zirconium metals is the subject of much study and development at the present time. Titanium metal can be produced by electric furnace methods, but the product is not of sufficient purity to be usable as such. It must be purified further, for example, by the iodide method. It is possible to produce comparatively pure metal by the reduction of the tetra chlorides of titanium and zirconium by the direct action of these vapors on molten metallic magnesium or sodium. Such processes as these have been investigated by the U. S. Bureau of Mines, and the magnesium process is actually conducted by E. I. Du Pont de Nemours on a semicommercial scale.

Metallic magnesium is apparently cheaper than metallic sodium for such chloride reduction. For example, the equivalent weight of magnesium is 12 and the metal sells for $0.205/lb. The equivalent weight of sodium is 23 and the metal sells for $0.18/lb. It was pointed out earlier in this paper that metallic sodium can be made more cheaply from sodium-amalgam than by the direct electrolysis of fused salt. Thus the ultimate choice of the reducing metal, from the standpoint of economics, has not yet been determined. There is the further possibility that sodium amalgam itself can be used for the reduction of titanium or zirconium chloride. If so, the cost of metallic titanium and zirconium would be still further reduced. One cannot help but feel that amalgam metallurgy will in some way play a part in the development of these two new metals —titanium and zirconium.

Conclusions

There is no sharp borderline between the fields of chemistry, electrochemistry and metallurgy. Processes which have been described for the utilization of the amalgam produced in an amalgam-type chlorine cell, involve problems of engineering peculiar to all three fields. The subject matter is therefore of interest to chemical engineers, electrochemical engineers and metallurgical engineers.

For the production of caustic soda one has the choice between the lime soda process, and the electrolytic process. Because of the increasing demand for chlorine in the United States, the electrolytic process is gaining in volume at the expense of the lime soda process.

For the production of electrolytic alkali, one has the choice of either the diaphragm cell or the amalgam cell. In the United States the overwhelming

majority of installations are of the diaphragm type; while in most other countries the reverse is true.

Since the market for chlorine in the United States is growing faster than the market for caustic alkali, the coincidental production of electrolytic alkali is becoming embarrassing. In the case of the electrolytic amalgam-cell process, however, there is the opportunity of making products other than caustic alkali. In Table 6 are listed the weights of raw materials and products equivalent to 2000 lb. of chlorine, for the various processes.

The potential market for these products can not even be estimated. The extent to which amalgam-cell technology may influence the imbalance between chlorine and caustic soda is thus a matter of conjecture (*21*). There is no question but that in specific instances use of the amalgam cell would solve the problem of a local inbalance between chlorine and caustic soda. Some of the applications of the amalgam cell are still in their infancy; great new industries may well be founded on its use.

Acknowledgment

The writer thanks W. C. Gardiner, R. A. Williamson and Olive B. MacMullin for help in the preparation of this paper; and the Mathieson Chemical Corp. for the release of heretofore unpublished information on several of its processes.

TABLE 6.

Raw Materials and Products Equivalent to 2000 Lbs. Chlorine
(Quantities Approximate)

Main Product	Lbs.	Co-Products	Lbs.	Raw Materials	Lbs.	DC Energy KWH
NaOH	2,250	H_2	56	NaCl	3,500	3,300
KOH	3,160	H_2	56	KCl	4,500	3,100
LiOH	1,350	H_2	56	LiCl	2,500	3,200
$NaOCH_3$	3,040	H_2	56	NaCl CH_3OH	3,500 2,220	3,300
$NaOC_2H_5$	3,840	H_2	56	NaCl C_2H_5OH Stabilizer	3,500 3,800 22	3,300
Na_2S	4,400			NaCl S	3,500 1,850	3,300
$Na_2S_2O_4$	3,430			NaCl SO_2 C_2H_5OH	3,500 3,700 200	3,300
$NaClO_2$	4,700	H_2SO_4 Na_2SO_4	10,100 4,800	NaCl $NaClO_3$ SO_2 H_2SO_4	3,500 6,800 3,200 8,000	3,300
$NaNO_2$	3,700			NaCl NH_3	3,530 1,010	3,300
H_2O_2	800	NaOH	2,250	NaCl	3,500	3,300
$(C_6H_5N)_2$	990	NaOH	2,250	NaCl $C_6H_5NO_2$	3,500 1,380	3,300
CHO·COONa	2,040	NaOH	1,460	NaCl $(COOH)_2$	3,500 2,040	3,300
Na(Dist'n)	1,300			NaCl Coal	3,500 7,300	(3,300)
Na(Elect.)	1,060	NaOH	410	NaCl Ca	3,500 6	4,830
Zn	1,840			$ZnCl_2$	3,900	3,400
Pb	5,830	Zn	3,900	$ZnCl_2$ Fe	3,900 5,850	3,400
Ti	1,300	NaCl	3,300	NaCl $TiCl_2$	3,500 3,200	3,300
Ti	450	NaCl	3,300	NaCl $TiCl_4$	3,500 2,700	3,300

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ELECTROLYTIC RECOVERY OF CHLORINE FROM HYDROGEN CHLORIDE

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Recovery of chlorine values from by-product hydrogen chloride by the Deacon process and by direct electrolysis is briefly discussed. An indirect electrolytic process is proposed which involves electrolysis in solution of a polyvalent metallic chloride, such as cupric chloride, to produce chlorine and a reduced metallic chloride. The reduced metallic chloride is oxidized with air and hydrogen chloride and recycled to the electrolytic step. Development of this process and plant requirements for commercialization are presented. Under the special circumstances where by-product hydrogen chloride is available and perhaps constitutes a disposal problem, where power is cheap and labor rates are no higher than average, where chlorine is in demand and the market for caustic soda is not particularly attractive, this process is believed to be the most economical one known for producing chlorine.

HYDROGEN chloride and hydrochloric acid are by-products of many important industrial processes, notably those involving substitution-chlorination of organic compounds. Production of this by-product acid normally exceeds demand. Many of these processes are not profitable unless value can be received from the by-product acid, and commercial exploitation of many additional chlorination reactions would be feasible if an economical process were available for the recovery of chlorine values from hydrogen chloride. Furthermore, such a recovery process would tend to relieve the existing imbalance between chlorine and caustic soda.

Deacon Process. The classical Deacon reaction for the oxidation of hydrogen chloride to chlorine and water is represented by the following equation:

$$2HCl + \tfrac{1}{2}O_2 \xrightleftharpoons{\text{Catalyst}} Cl_2 + H_2O \qquad (1)$$

This reaction is exothermic. An active oxidation catalyst and a high temperature are required for a practical rate of reaction. The reaction proceeds to equilibrium, resulting in contamination of the product chlorine with hydrogen chloride and oxygen (normally air). For example, with a 100% excess of oxygen, conversion of hydrogen chloride is 75% complete at 450° C., leaving 25% of the hydrogen chloride and the excess oxygen to contaminate the chlorine. The low quality of the product, need for extensive recycling of hydrogen chloride, the high temperature involved, and general complexity of the operation have combined to discourage commercial exploitation of the process. The relatively recent development of low-cost oxygen makes it possible to reduce contamination of the chlorine by substitution of this material for air as a source of oxygen. However, this development has not been sufficient to make the Deacon process a practical one.

Direct Electrolytic Process

The possibility of recovering chlorine values from hydrogen chloride by direct electrolysis of an aqueous solution has, of course, been recognized for many years. The basic reaction involved can be represented by the following equation:

$$2HCl \xrightarrow{\text{Electrolysis}} H_2 + Cl_2 \qquad (2)$$

This reaction has commercial possibilities and a substantial amount of development work has been done by the present investigators during recent years.

An electrolytic cell is shown diagrammatically as a part of the simplified flow sheet presented in Figure 1. A concentrated hydrochloric acid is fed to the cell on the cathode side of the diaphragm, percolates through the diaphragm, and flows past the anode. Generation of chlorine at the anode and hydrogen at the cathode partially depletes the electrolyte, and a relatively dilute hydrochloric acid flows from the cell. The dilute acid is refortified with hydrogen chloride and recycled to the electrolytic cell. The purpose of the cell diaphragm is to prevent mixing of the chlorine and hydrogen, and with an efficient diaphragm, chlorine containing less than 0.1% H_2 and hydrogen containing less than 0.2% Cl_2 has consistently been obtained.

The electrolytic process overcomes the principal difficulty encountered in the Deacon process by producing a substantially pure chlorine. It also has the advantages of moderate temperature and general relative simplicity. Although the direct electrolytic process is considered superior to the Deacon process, it still has a number of undesirable features. The problem of materials of construction for the electrolytic cell is a serious one. Power requirements for electrolysis are substantial, although considerably less, of course, than in the case of electrolysis of sodium chloride to produce chlorine. In the electrolysis of hydrochloric acid, all power costs must be charged against a single product, since, except under unusual conditions, the hydrogen must be considered a waste product.

Materials of Construction. Special materials of construction are, of course, required for the ordinary handling of hydrochloric acid. Requirements for electrolysis accentuate the problem. Graphite is the best anode material yet found. However, the graphite tends to soften and develop a "punky" texture with time. After a few months under the conditions shown in Figure 1, the anodes become so soft that they can be gouged out with the fingers. Work to be discussed later in this paper gave results which indicate that this deterioration may be substantially eliminated by proper control of electrolyte composition.

Graphite cathodes are not desirable for the direct electrolysis of hydrochloric acid due to the high overvoltage of hydrogen on graphite. However, use of graphite cathodes in Germany has been described by Gardiner (*1*). Copper and silver have been tested as cathode materials, with only limited success. Copper is rapidly attacked during any interruption in flow of current through the cell. Even under electrical load the copper tends to dissolve in spots and redeposit elsewhere in crystalline "trees." Silver gives better performance but is, of course, much more costly. Under electrical load, the acid leaving

the cell was found to contain about 0.5 mg. of silver/l. Upon interruption of the flow of current, the silver concentration rose to as high as 225 mg./l. Use of silver cathodes would require careful protection from load interruption.

The diaphragm material is exposed to strong oxidizing and reducing conditions and a strong acid, all at a temperature of about 80-90° C. It must be porous enough to permit flow of electrolyte without excessive pressure drop or electrical resistance, but must not be sufficiently porous to permit the passage of gas bubbles or to allow surges of electrolyte back and forth as a result of minor operating irregularities. Materials which have been tested include asbestos cloth, porous rubber, glass cloth, and glass cloth filled with barium sulfate. None of these materials was entirely satisfactory. A closely woven glass cloth (CSS-28, Owens-Corning Fiberglas Co.) gave best results. As pointed out, chlorine containing less than 0.1% H_2 and hydrogen containing less than 0.2% Cl_2 were produced. Unfortunately, however, the glass cloth was gradually attacked by the electrolyte, losing as much as 45% of its weight in 21 days of operation. With deterioration of the diaphragm, the purity of the gases decreased, as would be expected, eventually resulting in an explosion hazard. Some of the more recently developed highly resistant plastic materials might permit the fabrication of a satisfactory diaphragm. Successful use of polyvinyl chloride in Germany has been reported (*1*).

Power Requirements. Current efficiencies of substantially 100% have been measured. This must necessarily be the case when any diaphragm is used which will give chlorine and hydrogen of acceptable purity. The power consumption for electrolysis depends entirely, therefore, on the voltage requirements for the cell. Using a graphite anode, a silver cathode, the glass cloth diaphragm previously referred to, a current density of 100 amp./sq.ft., an anode-cathode spacing of 0.75 in., and a temperature of 80° C., a voltage of 2.25 v. was observed. Under these conditions the power requirement for electrolysis is 0.8 kw.hr./lb. of chlorine.

Metallic Chloride Process

Frank S. Low, who had been active in the work on electrolysis of hydrochloric acid, called to the attention of Westvaco the possibility of avoiding the principal difficulties encountered in the direct electrolysis by an indirect electrolytic process. This process involves the electrolysis of a solution of a polyvalent metallic chloride to produce chlorine and a reduced metallic chloride. The reduced metallic chloride is oxidized with air and hydrogen chloride to regenerate the oxidized metallic chloride, which is recycled to the electrolytic step. The basic reactions involved in this two-step process are illustrated by the following equations:

$$2CuCl_2 \xrightarrow{\text{Electrolysis}} 2CuCl + Cl_2 \qquad (3)$$

$$2CuCl + 2HCl + \tfrac{1}{2}O_2 \rightarrow \rightarrow 2CuCl_2 + H_2O \qquad (4)$$

Combining these two equations gives

$$2HCl + \tfrac{1}{2}O_2 = Cl_2 + H_2O \qquad (5)$$

This will be recognized as the familiar Deacon reaction. Equation 3 requires a relatively low voltage and Equation 4 represents a spontaneous exothermic reaction.

Other polyvalent metallic chlorides could, of course, be substituted for copper chloride. The principal requirement is that the oxidation-reduction potential of the metallic chloride be such that the power requirement for Equation (3) is not excessive and, at the same time, Equation (4) can proceed at a practical rate. Copper chloride is the preferred salt. Iron chloride is second choice, but has been found to be more difficult to oxidize and no easier to electrolyze. Also, there is a tendency under some conditions for a small amount of hydrogen to be generated at the cathode during electrolysis of ferric chloride. In the case of chromium chloride, the tendency toward hydrogen formation is much more serious. No trace of hydrogen has been found in the electrolysis of cupric chloride. For these reasons copper chloride was used in substantially all development work on the process.

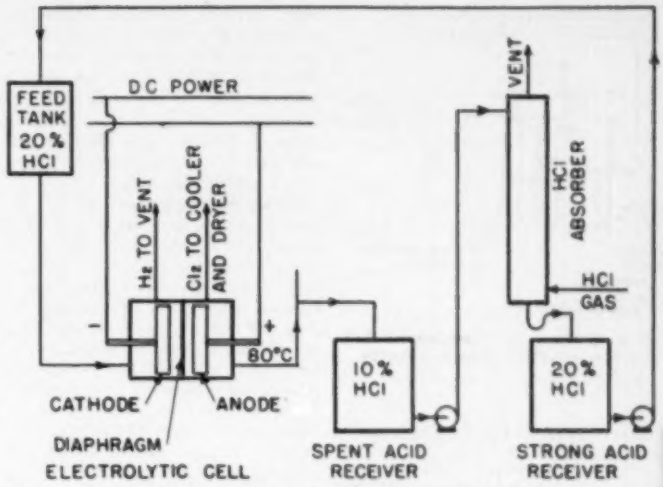

Fig. 1. Simplified Flow Sheet for Manufacture of Chlorine by Electrolysis of Hydrochloric Acid.

Although chemically equivalent to the Deacon reaction, the metallic chloride process has the advantage of producing chlorine in a pure form. The gas is not contaminated by the formation of an equilibrium mixture as in the Deacon reaction, and the nitrogen content of the oxidizing air is readily kept separate from the chlorine. The voltage and therefore the power requirements are much less for Equation (3) than for Equation (2) representing the direct electrolysis. No hydrogen is generated to contaminate the chlorine or to create a potential explosion hazard. The absence of a second gas in the electrolytic step simplifies the cell and eases the materials-of-construction problem. Patents covering the process have been granted to F. S. Low (*3*) and other patent applications are pending.

Problems faced in the development of the metallic chloride process were basically: (1) to devise a cell and develop operating conditions for electrolysis and to provide corrosion-resistant materials, (2) to find a means of oxidizing cuprous chloride with air at a practical rate, and (3) to provide for the removal of the water formed in Reaction 4 without loss of hydrogen chloride.

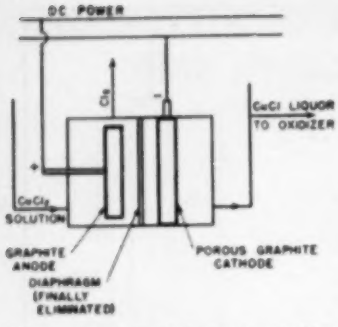

Fig. 2. Diagram of Experimental Cell for Electrolysis of Cupric Chloride

Electrolysis of Cupric Chloride

The basic elements of any electrolytic cell are: an anode, a cathode, an anolyte-catholyte separator, and a cell container. An arrangement of these elements which served as an effective small-scale experimental cell for the study of the electrolytic step is shown in Figure 2.

Anode. Ordinary electrode-grade graphite (Grade AGX, National Carbon Co.) was found to be entirely suitable for this application. Indications are that, with proper control of electrolyte composition, which will be discussed below, an indefinite anode life can be anticipated. Graphite anodes which had been in service for six months showed no signs whatsoever of any change from their original condition. They showed no change in weight, in water displacement, in electrical conductivity, or in visual appearance. During operation the cells showed no voltage trend, indicating the absence of any significant change in the surface characteristics of the electrodes. Such graphite anode permanence is believed to be unique in electrolytic chlorine generation experience.

Cathode. Graphite cathodes were found to be equally permanent and effective as the graphite anodes. The fact that no hydrogen is generated in this electrolysis eliminates the normal prejudice against graphite cathodes. Platinum probably is the only other cathode material which would be practical in this application, and there would appear to be no justification for the use of this relatively costly material.

Anolyte-Catholyte Separator. It is, of course, necessary to prevent reaction between chlorine generated at the anode and cuprous chloride generated at the cathode. Use of conventional diaphragms mounted between anode and cathode was first considered. The primary index of diaphragm performance is current efficiency. Diaphragms such as asbestos paper gave high current efficiencies of 94% or more, but were rapidly attacked by the electrolyte. The diaphragm material problem was substantially the same as in the case of the cell for direct electrolysis of hydrochloric acid just discussed.

By arranging the electrodes in a horizontal position with the anode located above the cathode, an effective diaphragm could be formed by placing a thin layer of granular material such as common silica sand or alundum sand over the entire cathode surface. High current efficiencies were obtained in this way and the granular diaphragms showed no attack by the electrolyte. However, this arrangement of the electrodes imposed certain limitations on cell design. At high current densities the chlorine tended to blanket the horizontal anode excessively, resulting in a voltage penalty. The voltage drop across the diaphragm itself was also appreciable. In spite of these disadvantages, a granular diaphragm of this kind might well be used if no more attractive alternative were available.

It was found that the diaphragm could be eliminated altogether by using a porous graphite cathode, through the pores of which the electrolyte flowed at a fairly high rate, carrying the cuprous chloride away as rapidly as formed at the cathode surface. Use of electrodes of this type in other applications has been previously suggested by Heise and Schumacher (*2*). Recombination of chlorine and cuprous chloride could not be completely prevented by this means. However, under the preferred operating conditions, current efficiencies as high as 90% were obtained. By eliminating the diaphragm, the voltage drop across the cell was substantially reduced. It was found that this more than compensated for the reduction in current efficiency, since the power requirement per unit of chlorine produced depends upon the product of voltage and current efficiency. Elimination of the diaphragm also greatly simplified cell design.

The effectiveness of the porous cathode as an anolyte-catholyte separator was found to depend upon the porosity of the graphite employed, rate of flow of electrolyte through the cathode, and the cathode current density. These three variables are closely interrelated. The cathode material finally selected after studying a variety of porosities was Grade 60 (National Carbon Co.).

Effect of Flow Rate. The effect of flow rate on current efficiency is shown in Figure 3. It will be noted that, for a given cathode porosity, current efficiency initially increases with increasing flow rate, as would be expected due to improved sweeping of the cathode face. A maximum current efficiency is reached beyond which the current efficiency tends to decrease. The solubility of chlorine in the electrolyte is small, but at the high flow rates enough dissolved chlorine passes through the cathode to more than offset any further improvement in current efficiency resulting from the improved sweeping.

The optimum flow rate for maximum current efficiency decreases as the porosity of the cathode is decreased. The maximum current efficiency increases appreciably with decreasing porosity. This trend does not continue indefinitely; little advantage is observed for cathodes less porous than Grade 50. Porosities of the cathode materials referred to in Figure 3 are shown in Table 1.

Cell voltage is also influenced by the flow rate through the cathode, as shown in Figure 3. Voltage decreases with increasing flow rate initially, and finally tends to level off. Increasing the flow rate reduces the cuprous chloride concentration at the active cathode face and increases the ratio of cupric to cuprous ions, both of which would be expected to affect the cathode potential in such a way as to reduce cell voltage. Since the power requirements for the cell depend upon the product of current efficiency and voltage, the optimum flow rate for minimum power consumption falls slightly above the optimum for maximum current efficiency.

Effect of Current Density. The voltage drop across the cell depends, of course, upon the current density at which the cell is operated. This relationship for an experimental cell is shown in Figure 4. The exact slope of the curve will be influenced by the details of cell design and the extent to which parasitic resistances have been minimized. It will be noted that voltage increases relatively slowly with increasing current density. The fact that no gas is generated at the cathode undoubtedly contributes substantially to this favorable relationship. The high conductivity of the electrolyte is also a contributing factor.

It was found that current efficiency was appreciably increased by increasing cathode current density. This relationship is shown in Figure 5. At the higher current densities a larger fraction of the cuprous chloride probably is formed within the pores of the graphite where sweeping efficiency is relatively high.

The increase in current efficiency with increasing current density tends to counterbalance the accompanying increase in cell voltage, thus minimizing the penalty in power consumption resulting from operation at high current den-

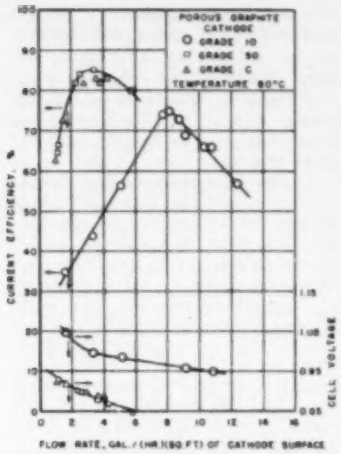

Fig. 3. Effect of Flow Rate on Current Efficiency and Cell Voltage

sities. This fact, coupled with the favorable voltage-current density relationship and the high cost of the corrosion-resistant cell parts, makes a high current density the most economical one. For the preferred cell design, which will be discussed below, the optimum current density was found to be about 400 amp./sq.ft. of cathode surface. This is a much higher current density than is normally used in industrial electrolysis. Chlorine-caustic cells ordinarily operate at current densities in the range 60 to 80 amp./sq.ft.

Composition of Electrolyte. The optimum electrolyte composition was found to be about 15% $CuCl_2$, 20% HCl, and 65% H_2O, although the cell is operable over a wide range of compositions. The conductivity of the electrolyte tends to increase with increasing hydrochloric acid content, but at concentrations much above 20%, the partial pressure of hydrogen chloride becomes sufficient to cause serious contamination of the chlorine with this material. Although the addition of cupric chloride to hydrochloric acid causes a decrease in conductivity, cell voltage is actually decreased slightly by increasing the cupric chloride content of the feed. This is probably due to a favorable effect on the ratio of cupric ions to cuprous ions at the cathode. It is apparent that sufficient cupric chloride must be fed to the cell to provide for electrolysis without deposition of metallic copper at the cathode. In any practical case, the cupric chloride concentration will be substantially above this minimum level, which depends upon current density and feed rate.

More important than the effect of electrolyte composition on power requirement is the effect upon anode life. Using the optimum electrolyte composition just indicated, no deterioration of the graphite anode of any kind could be detected, as previously pointed out. At a hydrochloric acid concentration of 13% the anode softens and cracks at a rapid rate; the deterioration is accelerated by further decrease in acid concentration. The presence of cupric chloride in the electrolyte has a beneficial effect, the minimum tolerable acid content being decreased by increasing the cupric chloride concentration. Mechanisms to account for these effects have not been definitely established. At low acid concentrations the electrolyte within the pores of the anode probably becomes depleted to the point where some oxygen is generated along with the chlorine. Any oxygen formed in this way will tend to oxidize the carbon. At higher acid concentrations the acid probably diffuses into the pores at a sufficiently high rate to prevent liberation of oxygen.

Temperature. The preferred temperature range in the cell is 80-85° C. Factors contributing to the selection of this range were: vapor pressure of hydrogen chloride, conductivity of the electrolyte, and solubility of chlorine in the electrolyte.

Cell Design. The all-important practical details involved in designing a commercial cell, such as provisions for delivering the electrical load to the graphite electrodes, feeding and distributing the electrolyte and removal of catholyte (cuprous chloride liquor), provision for escape of chlorine without back pressure, and the sealing of the various joints against penetration by the corrosive electrolyte, each presented problems which have been satisfactorily solved with the possible exception of the last item. Numerous cell designs are, of course, possible. A compact and effective design is shown in Figures 6 and 7.

An important feature of the cell is the hollowed-out monolithic cathode, 12 in. tall and 36 in. long. These cathodes are alternated with graphite anodes, the number employed depending upon the desired capacity of the cell. Using two cathodes and three anodes as shown in the figures, 10 sq.ft. of active cathode surface is available, giving the cell a capacity of 4000 amp. at 400 amp./sq.ft. The electrodes are held in the proper relative positions by two grooved Haveg end-plates, one at each end of the electrode assembly, and these are held in place by tie rods running the length of the cell as shown. The bottom edges of the electrodes are lightly plated with copper, and multiple heavy flexible copper straps are soldered to the plated surface at intervals along the length of each electrode to distribute the electrical load. These flexible straps are connected to the solid copper bus work shown in the figures. This relatively elaborate distribution system is necessitated by the high current density at which the cell is operated.

The electrode assembly rests upon ceramic insulators in a sheet steel cell container. A molten sealing material such as asphaltic pitch is poured into the container in such a way as to rise around the bottom edges of the elec-

TABLE 1.—PERMEABILITY OF POROUS GRAPHITE CATHODE MATERIALS

Based on Water at 21° C. Through Plate 1-in. Thick at 5 lb./sq.in.

Grade (National Carbon Co.)	Permeability gal./(sq.ft.)(min.)
10	175
50	30
60	14
C	0.30

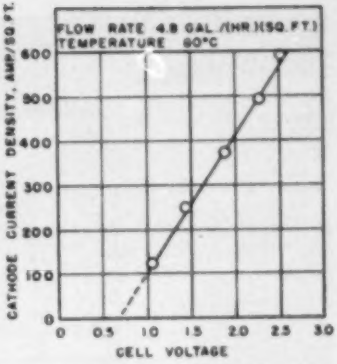

Fig. 4. Voltage vs. Current Density

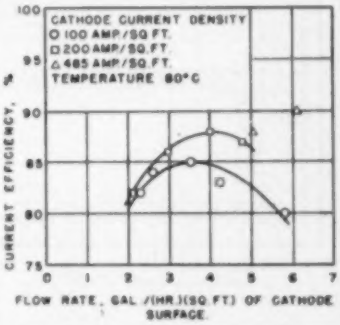

Fig. 5. Effect of Current Density on Current Efficiency.

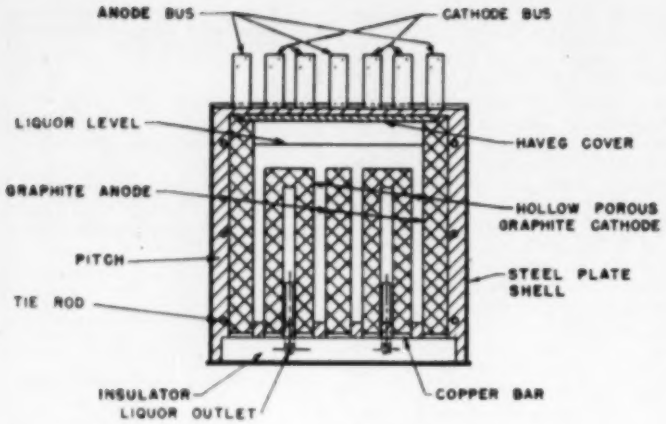

Fig. 6. Copper Chloride Cell, Section Through Short Dimension.

trodes, thereby sealing the lower joints exposed to the electrolyte. This first portion of sealing material is allowed to solidify, after which additional sealing material is poured into the space between the electrode assembly and the cell container, filling this space and flowing over the Haveg cell cover which is supported by the outermost anodes. This seals the remainder of the joints in the cell. The electrolyte is fed to the cell through a glass pipe extending through the cover at the center. Electrolyte flows through the walls of the porous cathodes into the hollowed-out portions, and from there through glass or Haveg pipe imbedded in the sealing material to a constant-level overflow device. Chlorine escapes from the cell through a second glass pipe mounted in the cell cover.

This completely sealed construction would not be feasible where periodic rebuilding or repair of the cells was required. However, the graphite electrodes and the Haveg end-plates give every indication of having an indefinite life, and with an adequate sealing material no periodic rebuilding should be necessary to realize a reasonable cell life. At present, no entirely satisfactory sealing material has been found, although a variety of asphaltic materials and related substances have been tested. After a few months of operation the sealing materials tested have failed due to attack by the electrolyte, permitting the electrolyte to reach the copper-graphite connections. The lower portions of the electrodes have been effectively impregnated with Halowax (a chlorinated naphthalene) to prevent penetration of the electrolyte through the pores of the graphite to the copper contacts. Failure occurs only as a result of penetration through the surrounding sealing material. It is anticipated that a satisfactory sealing material will eventually be found.

An alternative design has been worked out in which the electrodes extend through the cell cover, permitting electrical connection at the top of the cell beyond the reach of the electrolyte. This alternative design has the disadvantage of requiring substantially more costly graphite per unit of cell capacity. It also requires more power due to the appreciable voltage drop in the tall graphite electrodes. In view of these considerations, the bottom-connected cell discussed above is to be preferred if an adequate sealing material can indeed be found. Many other cell configurations can, of coruse, be devised. A cylindrical porous graphite cathode mounted inside and concentric with a cylindrical graphite anode has been tested and found to be an effective arrangement. Graphite costs in such a cell are, however, appreciably greater than those for the plate-type cell just discussed.

Figure 8 is a photograph of the electrode assembly for a 4000-amp. cell of the preferred design. Figure 9 shows the completed cell in a pilot installation. The outside container for this cell has the dimensions 19 in. by 47 in. by 19 in. tall. This cell produces 230 lb. of chlorine/day which makes it an extremely compact chlorine-producing unit.

Table 2 shows the operating characteristics of this cell. It will be noted that even at the extremely high current density employed, the power requirement of the cell is only 0.8 kw.hr./lb. of chlorine. This is low compared with 0.8 kw.hr./lb. of chlorine for the direct electrolysis of hydrochloric acid at 100 amp./sq.ft., and 1.3 kw.hr./lb. chlorine for electrolysis of sodium chloride at about 70 amp./sq.ft. The power requirements of these three types of chlorine-producing cells cannot be compared at a current density of 400 amp./sq.ft. since the two older processes are not operable at this level. At the less desirable current density of 100 amp./sq.ft., the power requirement for the copper chloride cell is 0.4 kw.hr./lb.Cl_2, or half the corresponding amount for direct electrolysis.

It will be noted that only about a third of the cupric chloride fed to the cell is reduced to cuprous chloride. This results from the fact that a high flow of electrolyte through the cathode is required for high current efficiency. It is more economical to recirculate substantial amounts of electrolyte than to accept a lower current efficiency.

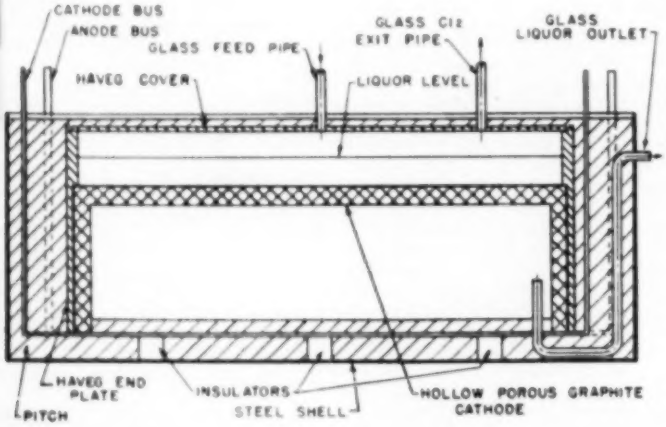

Fig. 7. Copper Chloride Cell, Section Through Long Dimension at Center of Hollow Cathode.

Oxidation of Cuprous Chloride

It is well known that cuprous chloride can be oxidized to cupric chloride by air. In alkaline solutions this oxidation is fairly rapid, but in acid solutions, as in the present case, the oxidation is notoriously slow. The oxidation reaction itself is rapid, but the passage of oxygen into solution is slow.

In investigating means of oxidizing cuprous chloride at a practical rate, the reaction was carried out in several different types of equipment including a packed column, a liquid column into which the air was introduced through a porous diffuser, and a turbine-type gas disperser. The air-liquid contact obtained in the packed column was found to be entirely inadequate, a commercial column of extremely large dimensions being indicated. Using a porous diffuser, oxidation at a practical rate could be obtained only if the dimensions of the diffuser were such as to give extremely small air bubbles. A fine alundum diffuser (Norton, Grade RA-98) was found to give an acceptable oxidation rate. However, a tendency was noted for cupric chloride to crystallize in the pores of the diffuser (undoubtedly due to localized evaporation of water), and it was felt that this might well prove to be a troublesome feature on a commercial scale.

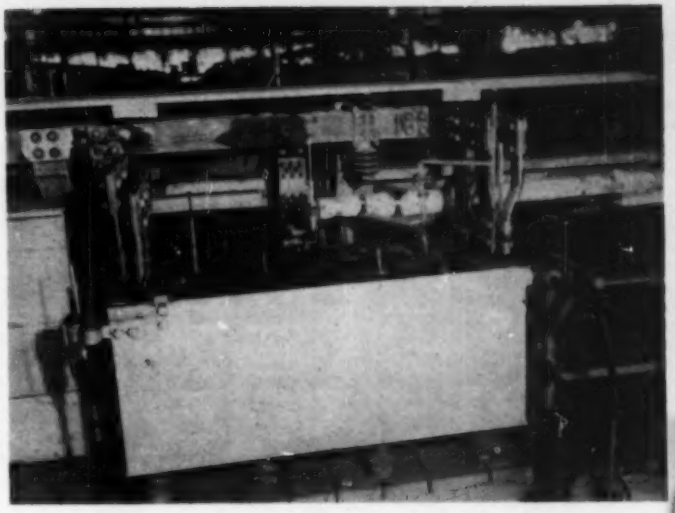

Fig. 9. Completed 4000-Ampere Copper Chloride Cell in Pilot Installation.

A gas-dispersing turbine was found to give satisfactory oxidation and was chosen as the preferred type of equipment. Figure 10 shows a typical batch oxidation curve using a turbine disperser. It will be noted that the rate of oxidation is independent of cuprous chloride concentration (as shown by the straight-line relationship) until the bulk of the cuprous chloride has been oxidized. Below a concentration of about 5 g./l., the rate of reaction is approximately proportional to the cuprous chloride concentration.

The oxidation was studied on a small pilot plant scale. The principal variables influencing rate of oxidation were found to be temperature, superficial air velocity (based on total cross section of oxidation tank) and power input to the disperser turbine. Substantially the expected relationships were found. That

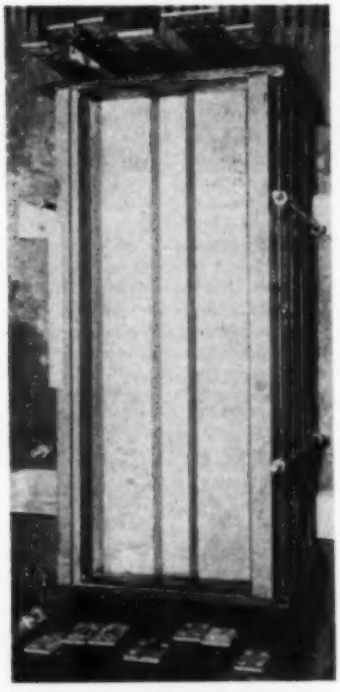

Fig. 8. Top View of Electrode Assembly for 4000-Ampere Copper Chloride Cell.

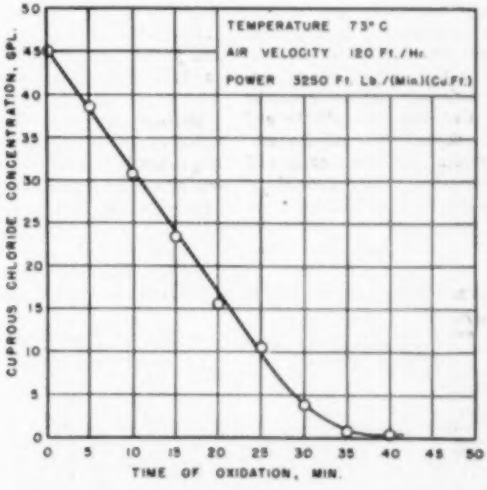

Fig. 10. Batch Oxidation of Cuprous Chloride Using Turbine-Type Air Disperser.

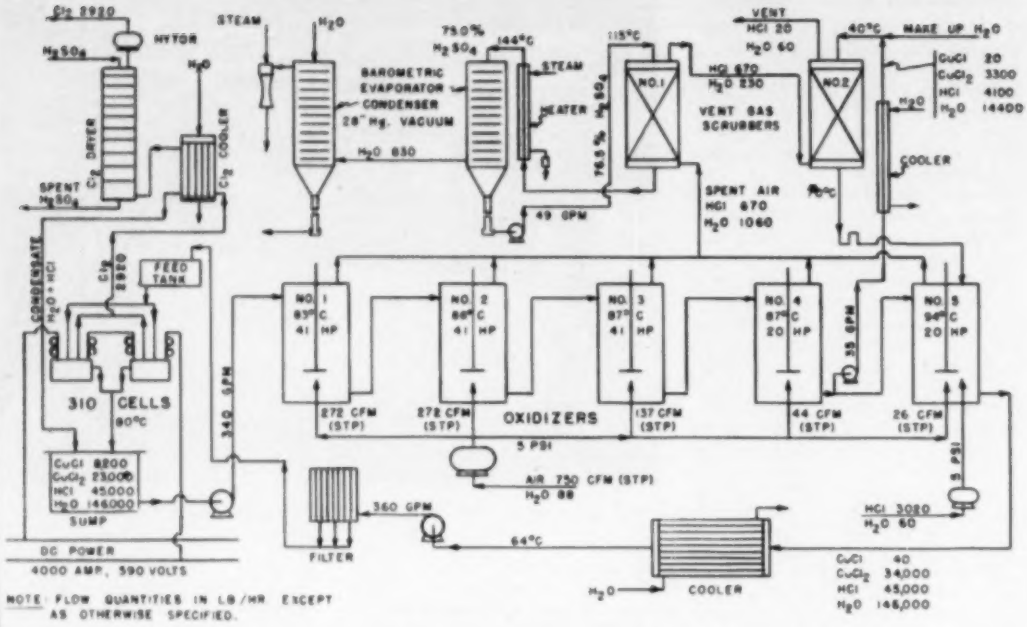

Fig. 11. Flow Sheet for Copper Chloride Process to Produce 35 Tons of Chlorine Per Day.

s, oxidation rate increased with increasing temperature, with increasing air velocity, and with increasing power input.

The maximum temperature is limited by the vapor pressure of hydrogen chloride. At temperatures above 90° C. the quantity of hydrogen chloride carried out by the oxidizing air becomes excessive. As previously pointed out, the oxidation reaction is exothermic, resulting in a temperature rise of several degrees during the course of the oxidation. Optimum air velocity and power input depend upon an economic balance between equipment costs and power consumption. The preferred air velocity was found to be 400 ft./hr. for the straight-line portion of the oxidation reaction, and to decrease during the remainder of the reaction, 40 ft./hr. being sufficient at a terminal cuprous chloride concentration of 0.2 g./l. This concentration corresponds to reoxidation of 99.5% of the original cuprous chloride. Optimum power input to the disperser turbine was found to be 3250 ft.lb./(min.)(cu.ft.) for the straight-line portion of the reaction, falling off to 1600 ft.lb./(min.)(cu.ft.) for the later stages.

Based on the slopes of the batch oxidation curves, it was calculated that five stages would be required for a continuous process using oxidation vessels of reasonable size. For a plant to produce 35 tons of chlorine/day, a liquid volume at each oxidation stage of 3000 gal. is required. Figure 11 shows a flow sheet for a 35-ton/day plant, including a preferred arrangement of the oxidizers.

It will be noted that the hydrogen chloride serving as the raw material for the process is introduced to the system at the No. 5 oxidizer. This material could be introduced before oxidation has begun, but it is preferred to keep the hydrogen chloride concentration as low as practicable in the early oxidation stages in order to minimize the quantity escaping with the oxidizing air. Absorption of the hydrogen chloride results, of course, in a substantial liberation of heat, but the quantity of electrolyte recirculated is sufficiently large that the temperature rises only a few degrees. The solution is cooled to about 64° C. before being returned to the electrolytic cells, in order to control cell temperature.

Repeated reference has been made to loss of hydrogen chloride with the oxidizing air. Handling of the gases leaving the oxidizers will be discussed in the following section.

TABLE 2.—OPERATING CHARACTERISTICS OF 4000-AMPERE COPPER CHLORIDE CELL

Feed Rate, gal./hr.	70
Feed Density, gal./(hr.)(sq.ft.)	7.0
Feed Composition: Cupric Chloride, %	15
Hydrogen Chloride, %	20
Feed Temperature, °C.	64
Cell Temperature, °C.	80
Current, amperes	4000
Cathode Current Density, amp./sq.ft.	400
Current Efficiency, %	82
Voltage Across Cell, v.	1.80
Power, kw.hr./lb. Cl_2	0.80
Chlorine Production, lb./hr.	9.6
Effluent Liquor Composition: Cuprous Chloride, %	3.7
Cupric Chloride, %	10.2
Hydrogen Chloride, %	20.2

Removal of Water of Reaction

As previously pointed out, water is

formed in the oxidation step according to the following equation.

$$2CuCl + 2HCl + \tfrac{1}{2}O_2 \rightarrow$$
$$\rightarrow 2CuCl_2 + H_2O \qquad (4)$$

One mole of water is formed per mole of chlorine produced, or 0.25 lb. of water/lb. of chlorine. It is obviously necessary to remove this water from the system in order to avoid progressive dilution of the electrolyte.

With the preferred electrolyte composition for best cell performance, and under the preferred operating conditions in the oxidizers, the spent air leaving the oxidizers carries somewhat more water out of the system than is formed during the oxidation step. Approximately 0.35 lb. of water/lb. of chlorine is removed in this way. This is not objectionable since it is simple enough to add make-up water to the system. However, the spent air leaving the oxidizers also carries a substantial amount of hydrogen chloride, corresponding to about 22% of the hydrogen chloride entering the system as raw material. These losses must, of course, be recovered under ordinary circumstances.

The ratio in the combined spent gases is about 0.63 lb. of hydrogen chloride/lb. of water. A strong acid containing about 38% HCl can, therefore, be condensed from these gases, and in some cases a market may be found for this material. In many cases, however, it will be desirable to return the hydrogen chloride values to the chlorine-producing system.

The water cannot be separated from the mixture by distillation due to the well-known existence of a constant boiling mixture. A number of schemes can be visualized for recovering the hydrogen chloride content of the spent oxidizer gases while eliminating the water, but in general these schemes tend to become complicated and costly in practice. The simplest process which has been considered so far involves dehumidification of the oxidizer gases with sulfuric acid, followed by absorption of the hydrogen chloride content of these gases in a cooled portion of the main recirculating electrolyte stream. A suitable arrangement of equipment for this purpose is shown in the abbreviated flow sheet of Figure 11.

The combined oxidizer gases pass to a packed column (No. 1) down which flows sulfuric acid of sufficient strength to remove approximately the desired quantity of water from the gases. This sulfuric acid is recycled through a vacuum evaporator, where the water taken up from the oxidizer gases is flashed off. This absorber-evaporator system is substantially adiabatic; introduction of only a small quantity of heat is required to replace radiation losses. By operating at moderate sulfuric acid concentrations (75.0 to 76.5% H_2SO_4) many difficulties normally attending the concentrating of sulfuric acid by evaporation are avoided. A barometric condenser and steam jet are employed to maintain vacuum in the evaporator.

Hydrogen chloride is recovered from the dehumidified gas leaving the sulfuric acid scrubber in a second packed column (No. 2). Electrolyte is taken from a point in the system where the hydrogen chloride concentration is at a minimum (preferably between Oxidizers No. 4 and No. 5), cooled with mill water to 40° C. in a heat exchanger and introduced at the top of the second column. Less than 1% of the hydrogen chloride entering the system as raw material is vented from the top of this column.

The chlorine gas leaving the electrolytic cells carries with it an appreciable quantity of water and hydrogen chloride. Composition of this gas is approximately 86% Cl_2, 2% HCl, and 12% H_2O on a weight basis. This gas is cooled and dried in conventional equipment of the type used for this purpose throughout the chlorine-caustic industry. A large fraction of the water condenses in the cooler, carrying with it the hydrogen chloride content of the gas. This dilute acid is returned to the circulating system. The amount of water which might be removed from the system at this point is not enough to compensate for the water formed in the oxidation reaction, and it is therefore considered preferable to remove all necessary water at the sulfuric acid scrubber. The cooled and dried chlorine is 99.5% to 99.9% pure and represents the finished product.

TABLE 3.—PROCESS REQUIREMENTS FOR COPPER CHLORIDE PROCESS

Based on Chlorine Production of 35 Tons/Day

Direct Supervision, Foreman	1
Operating Labor, Men/Shift	3
Maintenance Labor, Avg. Man-hours/day	40
Maintenance Materials—Cost Approx. Equal Maintenance Labor	
Hydrogen Chloride, ton/ton Cl_2	1.04
Cupric Chloride, lb./ton Cl_2	3.6
Sulfuric Acid, lb./ton Cl_2	82
Pure Water, 1000 gal./ton Cl_2	0.3
Mill Water, 1000 gal./ton Cl_2	82
AC Power, kw.hr./ton Cl_2	155
DC Power, kw.hr./ton Cl_2	1600
Steam, lb./ton Cl_2	2500

Plant Requirements for Copper Chloride Process

Reference has already been made to the flow sheet in Figure 11 for a plant to produce 35 tons of chlorine/day. Based upon the information gained in experimental work on this process, the highlights of which have been presented in this paper, and upon a considerable amount of experience in the field of industrial electrolysis, the operating requirements for such a plant have been estimated. Basic quantities required for estimating processing costs are presented in Table 3.

It is apparent that the actual processing costs will vary widely, depending upon the conditions existing at the site chosen for the plant. The principal factors influencing the cost of recovering chlorine from hydrogen chloride by this process are: unit cost of power, labor rates, and the charges which must be made for hydrogen chloride.

Under the special circumstances where by-product hydrogen chloride is available and perhaps constitutes a disposal problem, where power is cheap and labor rates are no higher than average, where chlorine is in demand and the market for caustic soda is not particularly attractive, the copper chloride process is believed to be the most economical method known for producing chlorine.

Acknowledgment

The work presented represents the efforts of a team. Frank S. Low was the first of the group to work in this field, and his efforts were greatly responsible for the interest in and advancement of the project. Substantial contributions by J. Beckenstein, R. M. Neel, W. B. Rose and R. G. Verdieck are also hereby acknowledged. The work was done with the facilities and under the auspices of the corporation's Westvaco chemical division.

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AZEOTROPE OF 1,1-DIFLUOROETHANE AND DICHLORODIFLUOROMETHANE AS A REFRIGERANT†

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IN the designing of a refrigeration system, it is customary, as the first step, to select a refrigerant and then design the equipment to fit the refrigerant. However, in the work described here the main objective was not to fit a machine to a refrigerant but rather to fit a refrigerant to an existing machine.

At the outset of this investigation, at least three distinct needs for new refrigerants were apparent:

1. A refrigerant which can be charged into a hermetic system, designed for Freon-12 (F-12) and 60-cycle current, so that the same refrigeration capacity will be available where 50-cycle current is used
2. A refrigerant which can produce an evaporating temperature at least 10 to 15° F. lower than that resulting in the use of F-12 in the same machine with the same condensing temperature and with the same compressor power
3. A refrigerant with 15 to 25% increase in refrigeration capacity over that of F-12 at the same operating temperatures so that some motors which do not now have complementary compressors can be used with existing compressors to get units with specific capacities not now available

While there are three definite needs, it is entirely possible that a single refrigerant will satisfy all the requirements. In each case, the refrigeration capacity must be increased so the initial effort centered around an attempt at a solution of the problem where 50-cycle current is employed.

The decrease in frequency from 60 to 50 cycles/sec. effects a corresponding decrease in the speed of the motor and, of course, in the speed of the compressor. A motor running at 1750 rev./min. on 60-cycle current will change to about 1460 rev./min. where 50-cycle current is used. If the refrigeration capacity for two refrigerants is the same, where used at the two different speeds, it follows that the one used at the lower speed will have about 20% higher capacity than the other at the same speed.

The primary objective then was to find a refrigerant whose capacity would be some 20% higher than that produced by *F*-12.

TABLE 1.—COMPOUNDS WITH BOILING POINTS NEAR −29.2° F.

	Boiling Points	
	°C.	°F.
Pentafluoromonochloroethane	−38	−36
Ethyl fluoride	−37.7	−35.9
Cyclopropane	−34.4	−29.9
Propadiene	−32	−26
Chloroethyne	ca−31	ca−24

† Complete paper, "The Evolution of a New Refrigerant," is on file (Document 2911) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Copies can be obtained by remitting 50 cents for a microfilm and $4.90 for a photocopy.

Search for a Conventional Refrigerant

With the criterion that the normal boiling point of the refrigerant had to be in the range −27.5 to −30.9° F., it might be thought that one need only turn to some handy reference book, such as the Handbook of Chemistry and Physics and select, from a few hundred compounds, a half dozen or so and begin testing them. He who approaches the problem in so hopeful a frame of mind is in for a real shock. Table 1 gives the data for all compounds, listed in the 30th edition of the handbook, which have boiling points close to the range −27.5 to −30.9° F.

Out of more than 9000 compounds, the list in Table 1 indeed looks anything but promising; cyclopropane is the only compound within gunshot of that desired. While its boiling point looks satisfactory, it is highly flammable and therefore would not be acceptable as a refrigerant.

Mixtures. With the dearth of encouragement where single compounds were considered, many mixtures were examined and it was finally found that there is a constant boiling mixture of dichlorodifluoromethane and unsymmetrical difluoroethane which boils at −27.9° F. The former compound is known in the trade as Freon-12 or *F*-12, the latter as Genetron-100 or *G*-100. The azeotropic mixture for use in refrigeration has been named Carrene-7 or *C*-7.

Samples for the early work on this binary system were made up of ingredients containing some air, therefore the azeotropic composition was found incorrectly to be 23.5% by weight of *G*-100. This value for a long time was accepted as the azeotropic composition at 32° F., but it is now known that the azeotrope contains a greater amount of *G*-100. The pressure-concentration curve, determined with a series of three mercury manometers, is so flat near the peak that pressure could not be used to set the azeotropic composition in the early work due to the fact that the variation is no more than 0.25 lb./sq.in. abs. throughout the range of 20 to 30% *G*-100 where the temperature is 32° F. Faith then was placed in the chemical analyses which were made by the gas density method.

With refinements in technique, it is possible now to use either pressure measurements or chemical analyses to fix the azeotropic composition. If pressure measurements alone are used, the composition can be found within 1.0%; chemical analyses will reduce this uncertainty to no more than 0.5% and perhaps to no more than 0.2 with the examination of sufficient mixtures. The refinements can be judged by the fact that *F*-12, purified by a technique re-

TABLE 2.—PRESSURE-CONCENTRATION IN *F*12-*G*100 SYSTEM AT 32.00° F.

		Vapor		
Mix No.	% *G*-100	Apparent Mole Wt.	% *G*-100	Lb./Sq In. Abs.
0	0.00	123.49	0.00	44.77
13	5.01	116.05	7.76	48.74
1	10.02	110.95	13.68	50.77
2	15.01	107.85	17.81	51.95
3	19.82	104.86	21.51	52.50
4	22.53	103.13	23.90	52.62
5	25.04	102.00	25.51	52.71
19	26.05	101.73	25.90	52.72
20	26.52	101.43	26.33	52.71
17	26.98	101.22	26.64	52.72
18	28.00	100.65	27.47	52.69
6	30.10	99.48	29.23	52.63
7	40.26	95.52	35.45	51.97
8	49.99	91.04	43.15	50.80
9	60.26	86.98	50.82	49.14
10	70.88	82.09	61.06	46.90
11	80.03	77.99	70.88	44.50
12	90.07	73.16	83.29	41.60
14	100.00	67.63	100.00	38.34

TABLE 3.—PRESSURE-TEMPERATURE OF CARRENE-7 (23.5% *G*-100)

T (° F.)	*F*-12 (lb./sq. in. abs.)	*C*-7 (lb./sq. in. abs.)	% Increase
32.0	44.77	52.70	17.72
39.2	50.96	60.01	17.76
46.4	57.75	68.03	17.80
53.6	64.70	76.30	17.93
60.8	73.35	86.47	17.89
68.0	82.24	96.04	18.00
68.0	82.24	96.04	18.00
60.8	73.35	86.46	17.87
53.6	64.70	76.32	17.96
46.4	57.75	68.05	17.84
39.2	50.96	60.02	17.74
32.0	44.77	52.69	17.70

cently described (*2*), gave, for a sample of 10, an average of 44.76 lb./sq.in.abs. at 32.00° F. No individual value differed from the average more than 0.03 and it is believed a lower range of variation could be obtained with suitable care.

G-100, purified in the same way, gave a pressure of 38.34 lb./sq.in.abs. at 32.00° F. and boiled at −11.5° F., where the pressure was 14.7 lb./sq. in.abs. The normal boiling point calculated from the pressures at 32.00° and 69.80° F. was −11.4° F.

In Table 2, the pressure-concentration relations for the system, *F*12-*G*100, can be found. Pressure values for the mixtures were obtained by adding the differential pressure to that of *F*-12 taken from the kinetic chart.

The data in Table 2 have been used to construct the phase diagram shown in Figure 1. One is immediately struck with the flatness of the rounded dome. All mixtures containing from 20 to 30% *G*-100 have pressures which do not differ much more than 0.1 lb./sq.in. from the average. This attribute is highly desirable for it means that the composition of Carrene-7 does not need to be precisely set. In fact, the indication is that all useful refrigaloys * will have this characteristic, if homoazeotropic.

* This term has been coined to apply to a refrigerant made up of two or more compounds.

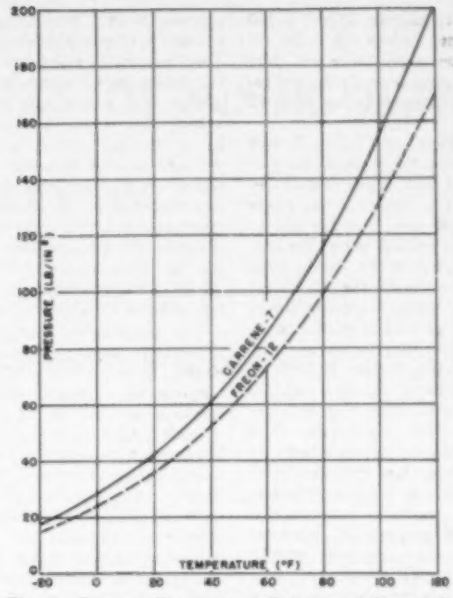

Fig. 2. Pressure-Temperature Relation of Carrene-7

From Table 2 and Figure 1, one may take the azeotropic composition at 32° F. as being close to 26% *G*-100 and 74% *F*-12 with an expected accuracy of something like 0.5.

All the test data pertaining to practical operations, however, have been obtained for a mixture containing 23.5% *G*-100. The pressure of this mixture at 32° F. is perhaps no more than 0.05 lb./sq.in. less than the maximum and, consequently, it may be just about as effective as the ideal mixture.

In making engineering tests, it has been desirable to have information on the pressure-temperature relationship of *C*-7. For the mixture containing 23.5% *G*-100, the data in Table 3 were found by differential measurements. The increase in pressure in per cent is a function of temperature and may be expressed as

$$P_i = 17.43 + 0.00833t \qquad (1)$$

where P_i is the increase in pressure in per cent and t is degrees Fahrenheit. It follows that

$$P_{C7} = P_{F12}\ (1.1743 + 0.000833t) \qquad (2)$$

Strictly speaking, Equation (*2*) applies

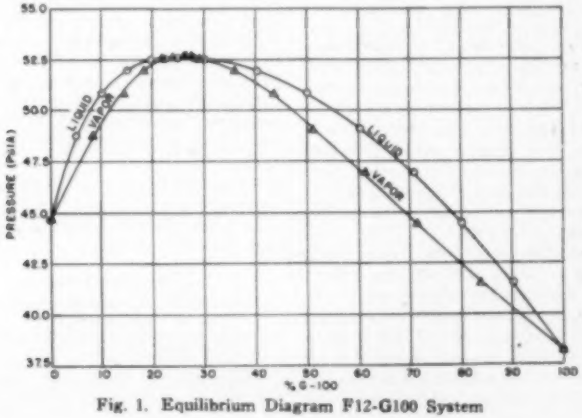

Fig. 1. Equilibrium Diagram F12-G100 System

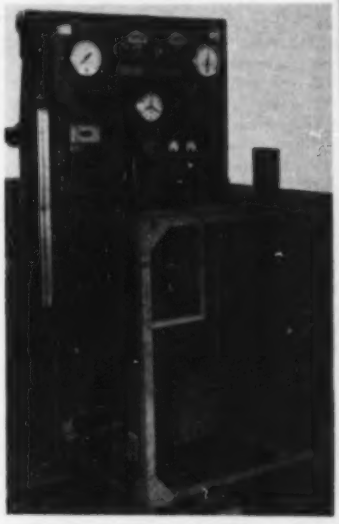

Fig. 3. The Calorimeter

to a mixture containing 23.5% *G*-100 and was obtained before the latest refinements in technique were put into practice. The pressure-temperature relation may be compared to that of *F*-12 in Figure 2.

An examination of Table 2 will quickly reveal that the composition giving the absolute peak in pressure cannot readily be chosen. There is no single value that stands out. Another glance at Figure 1 will remind one of the flatness of the dome of the curve. One can, however, estimate the azeotropic composition by taking a central figure for a symmetrical portion of the dome. From the table, it may be learned that a liquid containing either 22.53% or 30.16% *G*-100 has a pressure right at 52.62 lb./sq.in.abs., some 0.10 lb./sq.in. lower than the peak of the curve. The average of these two percentages is 26.4% *G*-100 and represents the azeotropic composition as determined in this crude manner.

The chemical analyses of mixtures close to this composition can now be used to get a probably more accurate value. Table 4 has been developed from a portion of the data in the preceding table.

It is rather simple to deduce that the ideal mixture-composition to complete the table must be between 25.04 and 26.05, probably much closer to the higher value. If one could use proportionality in the differences so as to get a composition corresponding to a difference of 0.00, the value of 25.8% *G*-100 would represent the azeotrope. On the evidence at hand, this value is accepted as being within at least no more than 0.5% of the true value.

Refrigeration Capacity Tests. Before the better value for the azeotropic composition was known, quantitative tests were carried out in two ways to establish the refrigeration capacity of the refrigaloy containing 23.5% *G*-100. A refrigeration calorimeter with a 1-hp. compressor was used and also a 3-hp. self-contained air-conditioning unit. In each case, the evaporating and condensing temperatures were held at 40 and 105° F. respectively.

The calorimeter is shown in Figure 3. It is a secondary refrigerant-type calorimeter of 12,000 B.t.u./hr. capacity and consists primarily of a direct expansion coil located in a carefully insulated pressure vessel. Heat is applied to the primary refrigerant flowing through the direct expansion coil by means of electric heater coils through the medium of a secondary refrigerant sealed in the vessel. The heater coils are controlled by a Mercoid switch actuated by a pressure bellows connected to the secondary refrigerant, thereby providing direct control of the secondary refrigerant pressure, and indirectly the temperature of the primary refrigerant leaving the calorimeter. The pressure of the primary refrigerant is controlled by a manual expansion valve.

TABLE 4—PERCENTAGE *G*100 NEAR AZEOTROPIC COMPOSITION

Mix No.	% *G*100 Liquid	Vapor	Differences
4	22.53	23.90	+1.37
5	25.04	25.51	+0.47
Ideal			0.00
19	26.05	25.90	−0.15
20	26.52	26.33	−0.19
17	28.98	28.64	−0.34
18	28.00	27.47	−0.53

The compressor capacity is determined by measuring the heat input to the electric heaters. Accurate pressure and temperature measurements determine the entering and leaving conditions of the refrigerant. A dynamometer is used in conjunction with the calorimeter to determine power input to the compressor. The condenser is used to maintain high-side conditions, and to liquefy the primary refrigerant.

In the first comparison, the compressor was run at a speed of 1600 rev./min. for both *F*-12 and *C*-7. The increase in refrigeration capacity varied from 16.7 to 17.0%. The *C*-7 was tested at 1330 rev./min. to simulate a condition where a change may have been made to 50-cycle current. The increase in capacity over that for *F*-12, scaled down by proportion from the 1600 rev./min. level, was 18.8%. In other words, there is greater efficiency as the speed is lowered.

In the tests involving the 3-hp. air-conditioning unit, the compressor again was run only 5/6 as fast where the *C*-7 was tested. There was no discernible difference in capacity of the two refrigerants. In other words, the *C*-7, where used in a machine with 50-cycle current, gives almost the same capacity as *F*-12 does in the same machine with 60-cycle current. In all tests, the power required for a unit of refrigeration was practically the same.

General Attributes of Carrene-7. There are certainly many factors, other than refrigeration capacity, to be considered before a new refrigerant can be adopted for wide use. Among these factors are melting point, chemical stability, corrosivity, flammability, toxicity, behavior with oils, as well as certain thermodynamic properties which contribute to efficiency.

The melting point of *C*-7 is probably as low as *F*-12 and for this reason would doubtless be satisfactory.

Chemical stability tests have been conducted in rough manner by heating *G*-100 and *C*-7 in steel cylinders so as to have a reflux action continuously and periodically. Water, and sometimes air, was used along with a fairly large group of metals, including aluminum. The maximum temperature was around 150° F. There was no change in the amount of noncondensables nor was there any evidence of corrosion.

In addition to the corrosion tests already mentioned, a group of metals including copper, brasses, steel and aluminum was put in the vapor and liquid space on the high temperature side of a 3-hp. air-conditioning system. The unit was run so that the superheated refrigerant vapor was close to 200° F. There was no indication of any appreciable corrosion of the test coupons nor was there any trouble with the compressor.

Genetron-100 itself is flammable, but all attempts to burn Carrene-7 where the percentage of *G*-100 was held as low as 27% failed even when the refrigerant was preheated to some 300° F. No tests were made involving a higher percentage of *G*-100.

No tests have been conducted in this laboratory on toxicity. However, it has been reported by Knapp (*1*) that the toxicity of Genetron-100 is intermediate between *F*-11 and *F*-12 and probably somewhat closer to *F*-12 since its acute toxicity is considerably less than that of *F*-11. There can be little doubt then that *C*-7 will meet the needs and requirements from this standpoint.

Supplementary information is now being obtained through field tests and the program will be made more extensive as the refrigerant becomes more plentiful. It is not yet available in substantial commercial quantities.

Acknowledgments

The writers are deeply grateful for the cooperation afforded by Kinetic Chemicals, Inc., in furnishing the supply of 1,1-difluoroethane used in the early part of this investigation, including the calorimeter tests. Likewise, an expression of appreciation is being made of the cooperation of the General Chemical Co., who provided the Genetron-100 which was used in the later work. There are too many people in Carrier Corporation to whom the authors are indebted to attempt to give all individual recognition. Attention, however, must be called to C. M. Ashley for his advice and encouragement; to Michael Kin for his able and reliable assistance in helping to carry out the experimental work; and to T. G. Foster who made the refrigeration capacity tests.

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1. Knapp, W. A., General Chemical Co., Private Communication.
2. Pennington, W. A., *Refrig. Eng.*, **58**, 261 (1950).

(*Presented at Thirteenth Regional Meeting, Houston, Tex.*)

POWER CHARACTERISTICS OF MIXING IMPELLERS

PART II†

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Flat-Blade Turbines. The flat-blade turbine shown in Figure 7 and detailed in Figure 8 is typical of radial flow turbines.

Table 2 shows the many sizes of flat-blade turbines used and the various conditions of environment studied. Data typical of the very large number of experiments performed are given in Table 5 for a 6-in. diameter six-flat-blade turbine in an 18-in. tank. Data are for operation without baffles and also with four 10% baffles. Summary data for all results with flat-blade turbines are given in Table 6. Data of Table 5 are all summarized in two lines of Table 6 for the 6-in. turbine.

Turbines Without Baffles. Figure 14 shows a plot of the data of Table 5 and other data not listed. Correlation of data for operation without baffles (curve 4) is handled in the same way as outlined previously for propellers. When a turbine is rotated in a liquid of low viscosity in a smooth wall vertical cylindrical tank, the flow pattern is the same as for the propeller in Figure 3. The force of gravity plays a role in such fluid motion, and the Froude number is used to correlate data at Reynolds numbers above 300. For such Reynolds numbers Equation (5) can be used and the values of the exponent n for this and a 4-in. turbine may be computed from the data in Table 4. These values were computed from the experimental data. At low Reynolds numbers Curve 4 coincides with those for operation with baffles, and in the viscous range the slope of the line is -1 and Equation (8) applies. The value of K can be found from Table 6 as described above for the propeller. The shape of the curve is similar to that of a high pitch propeller (Fig.13), and it can be approximated by use of the ϕ value at the three characteristic Reynolds number points.

The maximum power input that can be achieved with a turbine operating without baffles occurs when the vortex formed by the swirl just reaches the turbine. Hence, there is a limit to the amount of power that can be imposed in such a system (14).

Turbines with Baffles. The other curves of Figure 14 show the effect of three different baffle widths. When baffles are used to prevent swirl and vortex formation the resultant flow pattern is as illustrated in Figure 6. This flow pattern has vertical and lateral flow currents that are desired for most mixing operations. Under these conditions much more power can be imposed by increasing turbine speed than can be accomplished in unbaffled conditions. Data are plotted with power number as ordinate; the data fall on single lines and show that Equation (6) can be used to correlate the data.

The shape of the baffled operation curves shows the typical viscous flow conditions at Reynolds numbers below 10. As Reynolds number is increased, transition of flow takes place and the slope of the curve increases from -1 to zero. A minimum point in the curve is reached at N_{Re} of 200; such a minimum in the curves was found in the data for other impellers, as can be seen in the curves of Figure 15. The reference Reynolds number of 200 was selected as a characteristic because of this behavior. After the minimum the curves rise and the slopes of the lines have small positive values. The lines rise depending on the width of the baffles as shown by curves 1, 2, and 3. For baffles 10% of tank diameter the curve reaches a slope of zero at a Reynolds number of 10,000 and remains so up to 1,000,000. For the 4% baffling the curve rises only slightly above the minimum at N_{Re} of 200. This curve reaches a slope of zero at a Reynolds number of 2,000 and remains so far the remainder of the curve. Equation (10) applies to the turbulent range and the value of K is equal to ϕ at N_{Re} of 100,000.

All these curves can be approximated closely by knowing the values of the power number at the three characteristic Reynolds numbers of 5, 200, and 100,000. And the power number — Reynolds number curves can be drawn as outlined above for propellers.

All data for flat-blade turbines are summarized in Table 6. These data cover turbine sizes from 3 in. to 48 in. diameter, and all (for the six-blade turbines) are represented by the one curve, number 6 of Figure 15.

Other Impellers and Comparisons. The study of various impellers is outlined in Table 2. Data for all of them may be correlated by the use of Equations 5 and 6. Data are given in Table 6 for the three characteristic Reynolds numbers by which the $\phi = N_{Re}$ plots may be approximated. Typical curves showing the characteristics are given in Figure 15. Data used in these curves are for the same ratios of T/D, H/D, and C/D.

A comparison of the curves of Figure 15 will serve to show the differences in behavior of the various impellers and the equations which apply at the different Reynolds number ranges. The actual vertical position of the curves is of less importance than the shape of the curve. The vertical location will vary with impeller shape, but it would be possible to move any of the curves verti-

† Part I of this paper appeared in the August issue.

‡ Also Illinois Institute of Technology, Chicago, Ill.

NOTE: Table 2, Summary of Experimental Operations, and Table 7, Data on Flat Six-Blade Turbines, 10% Baffles, are on file (Document 2860) with the American Documentation Institute, 1719 N Street, N.W., Washington 6, D. C. Data can be obtained by remitting 50 cents for a microfilm and 50 cents for photoprints.

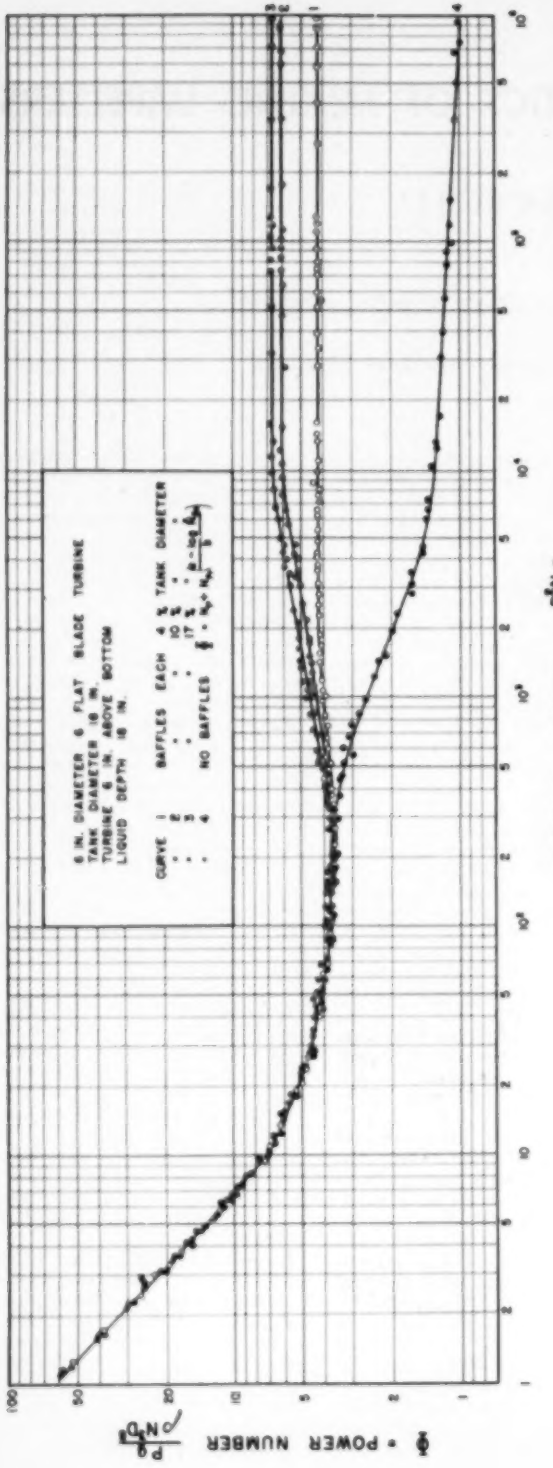
6 IN. DIAMETER 6 FLAT BLADE TURBINE
TANK DIAMETER 18 IN.
TURBINE 6 IN. ABOVE BOTTOM
LIQUID DEPTH 18 IN.
CURVE 1 BAFFLES EACH 4 % TANK DIAMETER
2 " " 10 % " "
3 " " 17 % " "
4 NO BAFFLES
REYNOLDS NUMBER $\frac{D^2 N \rho}{\mu}$
POWER NUMBER $\frac{P g_c}{\rho N^3 D^5}$

Fig. 14. Reynolds Number Correlation for a Flat Blade Turbine.

cally by changing impeller dimensions (other than impeller diameter) such as blade width and blade length.

All impellers gave data showing viscous flow conditions at Reynolds numbers below 10. Equation (8) applies and K can be evaluated from Table 6.

All impellers when operated with baffles or their equivalent give correlation curves of zero slope at high Reynolds numbers. Some reach zero slope and turbulent flow at lower Reynolds numbers than others. In the range of zero slope, Equation (10) applies, and K is equal to the power number; it is the value ϕ at N_{Re} of 100,000 in Table 6.

When the impellers are operated without baffles, the curves (for all data herein reported) never quite reach a constant slope. Hence, the constants in Equation (4) are variable and little is gained by evaluating them for point conditions.

Between viscous flow conditions and the final slope of zero in the turbulent range, there are transition ranges of various lengths. There is little to be gained in evaluating the point-by-point constants of Equation (7) for this transition range, but the equation can be solved for P, if desired, by substituting the slope of the line for the exponent m.

Curves 1, 2, 3, and 4 give the characteristics for the familiar Marine-type three-blade propeller. The square-pitch propellers show the greatest range of power requirement between the Reynolds number extremes on the plot, e.g., for baffled operation, between N_{Re} of 10^6 and 2, the power (equivalent to N_p) increases from about 0.2 to 20, or a one-hundred-fold increase. The higher pitch propellers have a considerably lower power range requirement than the lower pitch propellers.

Curves 5 and 6 are for the six flat-blade turbines and have been shown in Figure 14. These impellers show the smallest spread in power over the Reynolds number extremes, e.g., for baffled operation. Curve 5 between N_{Re} of 10^6 and 2 shows a power increase from 6 to 35, or about a sixfold increase. However, there is a minimum power number point of about 3.4.

The fact that curve 6 has such a low power spread between the turbulent and viscous extremes is important. Consider a turbine operating in a liquid whose viscosity is one centipoise and the density, speed and diameter are such that the Reynolds number is 10^6. The power number is 6.3. If the density of the liquid and the speed of rotation and diameter of the impeller are held constant, an increase in viscosity will decrease the Reynolds number. Accordingly, if the viscosity is increased

to ten centipoises, N_{Re} becomes 10^5 but the power number remains the same, namely 6.3. Thus, the power required to turn the turbine at the same speed remains constant. This is also evident from Equation (10) which applies to this range, since viscoscity is not a part of the equation. If viscosity is further increased, say to 100 cps., N_{Re} becomes 10^4, and the power number and power are still the same. When the viscosity is increased to 1000 cps., N_{Re} becomes 10^3 but the power number is smaller, 4.3, and it actually requires less power to turn the turbine at the same speed. If the viscosity is further increased to 10,000 cps., N_{Re} becomes 10^2 and the power number is 3.7, showing even less power required. Increasing the viscosity still further to 100,000 cps., N_{Re} becomes 10 and the power number is 7.5. Here the power increases with viscosity; this is also evident from Equation (8) which contains the viscosity but not the density, and this equation applies in the viscous range.

From this it is clear that a flat-blade turbine running at constant speed in baffled conditions can be operated in liquids of widely different viscosities, from the lowest (at high Reynolds numbers) to very high values, without increasing the power requirement. For curve 6 the power does not increase from N_{Re} of 10^6 to N_{Re} of 15; this represents a very considerable viscosity range. Thus, these impellers are adaptable to many fluids and may be used at constant speed without fear of overloading the motor drives. This phenomenon is referred to as a flat power characteristic; such a characteristic is very desirable and is a function of impeller design and the amount of baffling.

It should be noted that there is a minimum power occurring at a Reynolds number of 200 for the flat-blade turbine. If a turbine (or a paddle, see curve 10) is operating at N_{Re} of 200, it is possible to increase the power demand on the driving motor by increasing or decreasing the liquid viscosity, because the power number will increase for either an increase or a decrease of the Reynolds number. If the driving motor is operating at full load at N_{Re} of 200, it will be overloaded and possibly will burn out if the liquid viscosity is changed. In the infrequent case where it is unavoidable to operate at N_{Re} of 200 the driving motor is usually sized to handle the power demand equiavlent to that at N_{Re} of 10^5.

Comparing curve 6 with curves 2 and 4 for propellers, it is seen that the turbine will operate without increase in power demand over the widest range of viscosities; the high-pitch propeller over a smaller range; the square-pitch propeller over the smallest range.

The curved-blade turbine of Figure 9 is characterized by curve 7 of Figure 15. This impeller has the same highly desirable flat power characteristics as the flat-blade turbine just described. Equations 8 and 10 apply at the appropriate ranges of the Reynolds number, as in the case of the flat-blade turbine.

The arrowhead turbine of Figure 10 is characterized by curve 8, Figure 15. This turbine has similar characteristics to the flat-blade turbine. Equations 8 and 10 apply as for the flat-blade turbine.

The fan turbine of Figure 2, made of eight blades, blade width ¼ blade length, and blades set at a 45° angle, is characterized by curve 9, Figure 15, and by the fact that it is an axial flow impeller, like the propeller, unless operated close to a tank bottom. It has almost the same power characteristics as the high-pitch propeller, and is not as desirable as the flat-blade turbine for adaptability to changes in liquid viscosity. Equation (8) applies at Reynolds numbers below 10, and Equation (10) at Reynolds numbers above 2000. Values of K may be computed from Table 6.

Curve 10 is for the flat-blade paddle (a single paddle having two blades). The length of the blade is one-half paddle diameter, and the ratio of the length of blade to width of blade is three. The paddle has good power characteristics. The spread in power number between the extremes of Reynolds number is however much larger than that for the flat-blade turbine. A minimum point in the curve occurs at N_{Re} of 200, just as for the flat-blade, curved-blade and arrowhead turbines. Equation (8) applies below Reynolds number of 10, and Equation (10) above Reynolds number of 3000. Values of K may be computed from Table 6.

The shrouded six-blade turbine of Figure 11 was used with baffles in curve 11, Figure 15, and with a stator ring containing twenty blades in curve 12. The ring for a 4-in. turbine was 4⅛ in. I.D., 6⅜ in. O.D. and contained 20 curved blades, each 1¼ in. high. The small blades attached to the stationary ring act as baffles. In this position the baffles are close to the impeller rather than at the tank wall. With wall baffles the shrouded turbine has power characteristics much like the square-pitch propeller, although the flow pattern is radial and not axial like the propeller. There is only slightly less spread in power number over the extreme range of Reynolds numbers than for the square pitch propeller, and a greater spread than for the higher pitch propellers. Curve 12 differs noticeably from curve 11 at low Reynolds numbers, but both curves coincide over a wide range and differ only slightly from curve 2 for the square-pitch propeller. It is evident that this shrouded impeller is not so widely adaptable as the other turbines and has the same limitations as the propeller. Equation (8) applies in the viscous range, and Equation (10) applies above a Reynolds number of 30,000.

Curves 13 and 14 of Figure 15 are calculated from the data of Miller and Mann (*9*) and of White and Sumerford (*18*). These curves are in general agreement with the others. They comprised data for operation without baffles and have the characteristic shape except that lines of constant slope were obtained and the Froude effect was not taken into account.

Effect of Fluid Properties and Variables

Effect of Viscosity. The effect of viscosity on power consumption is not only dependent on the Reynolds number but also on the impeller shape and baffling. From previous discussion it is clear that the different impellers give differently shaped Reynolds number correlation lines. The comparison curves of Figure 15 show directly how viscosity can affect the power requirement for each impeller when it is the only variable. Characteristics as shown in lines like curves 1, 2, 3, 4, 5, and 11 indicate that as viscosity increases power consumption also increases and does so at increasing rate until the maximum in the viscous region where Equation (8) holds.

There are impellers, however (curves 6, 7, 8, 9, 10), which can be operated so that an increase in viscosity causes no increase in power consumption over a considerable range. Here Equation (10) holds. In fact, in some cases the required power actually decreases. Impellers whose characteristics may be correlated by Equation (10) and which give curves like 6, 7, 8, 9, and 10 are said to have good viscosity tolerance. They are desirable for applications where liquid viscosity may vary widely. Low-pitch propellers or other impellers giving characteristic lines which slope in the turbulent range are less desirable for use if the viscosity is to be varied.

Whenever the Reynolds number is less than 10, viscous flow predominates and power is directly proportional to viscosity as shown in Equation 8.

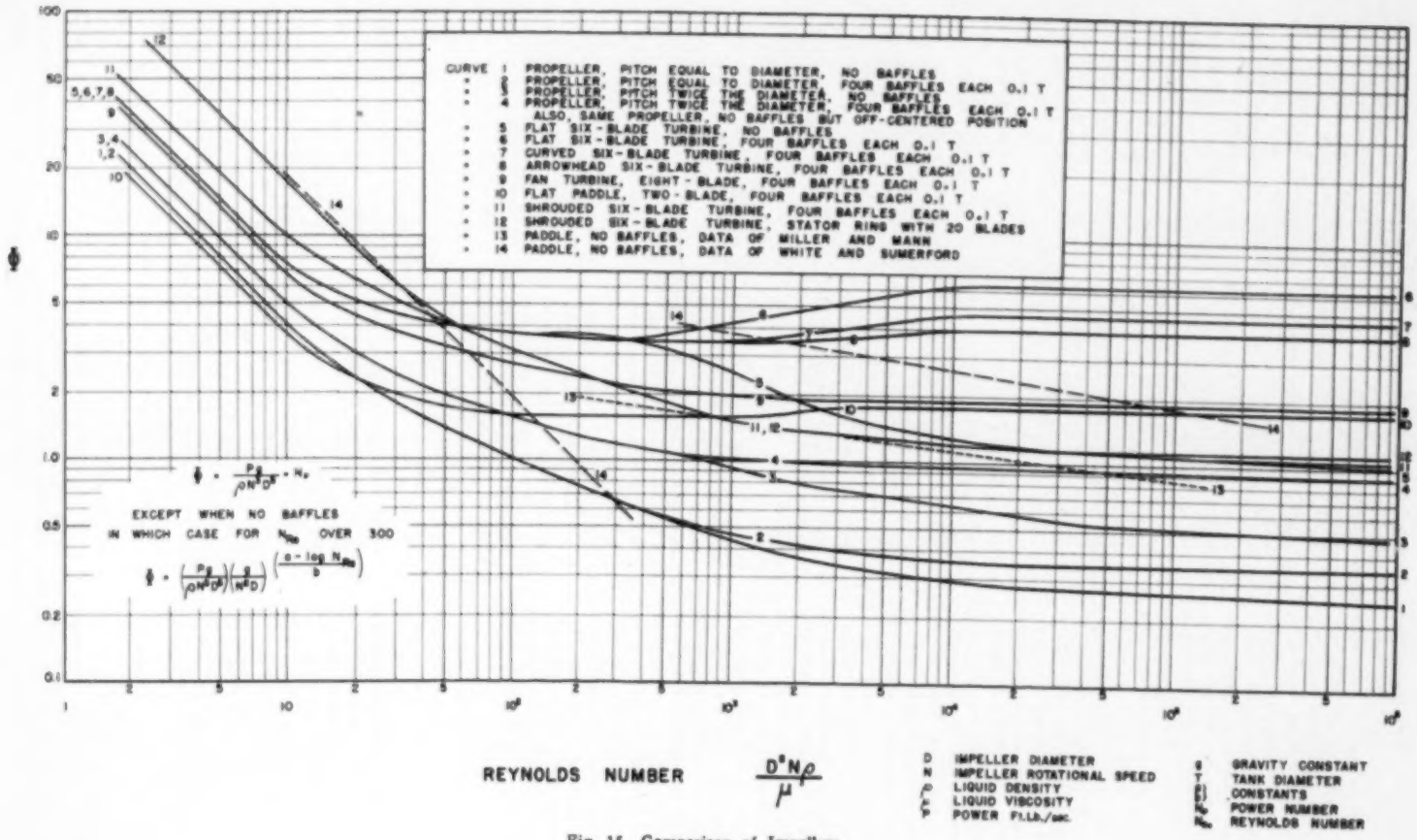
CURVE 1 PROPELLER, PITCH EQUAL TO DIAMETER, NO BAFFLES
" 2 PROPELLER, PITCH EQUAL TO DIAMETER, FOUR BAFFLES EACH 0.1 T
" 3 PROPELLER, PITCH TWICE THE DIAMETER, NO BAFFLES
" 4 PROPELLER, PITCH TWICE THE DIAMETER, FOUR BAFFLES EACH 0.1 T
ALSO, SAME PROPELLER, NO BAFFLES BUT OFF-CENTERED POSITION
" 5 FLAT SIX-BLADE TURBINE, NO BAFFLES
" 6 FLAT SIX-BLADE TURBINE, FOUR BAFFLES EACH 0.1 T
" 7 CURVED SIX-BLADE TURBINE, FOUR BAFFLES EACH 0.1 T
" 8 ARROWHEAD SIX-BLADE TURBINE, FOUR BAFFLES EACH 0.1 T
" 9 FAN TURBINE, EIGHT-BLADE, FOUR BAFFLES EACH 0.1 T
" 10 FLAT PADDLE, TWO-BLADE, FOUR BAFFLES EACH 0.1 T
" 11 SHROUDED SIX-BLADE TURBINE, FOUR BAFFLES EACH 0.1 T
" 12 SHROUDED SIX-BLADE TURBINE, STATOR RING WITH 20 BLADES
" 13 PADDLE, NO BAFFLES, DATA OF MILLER AND MANN
" 14 PADDLE, NO BAFFLES, DATA OF WHITE AND SUMERFORD
EXCEPT WHEN NO BAFFLES
IN WHICH CASE FOR N_{Re} OVER 300
REYNOLDS NUMBER $\frac{D^2 N \rho}{\mu}$
D IMPELLER DIAMETER
N IMPELLER ROTATIONAL SPEED
ρ LIQUID DENSITY
μ LIQUID VISCOSITY
P POWER Ft.Lb./sec.
g GRAVITY CONSTANT
T TANK DIAMETER
a, b CONSTANTS
N_p POWER NUMBER
N_{Re} REYNOLDS NUMBER

Fig. 15. Comparison of Impellers.

Effect of Liquid Density. The power number – Reynolds number plots all show lines with slope of −1.0 in the viscous range. Thus, for Reynolds numbers below 10 density has no effect on the power requirements of impellers. This is shown by Equation (8).

When impellers operate in the transition and turbulent ranges, density has an effect. In the turbulent range when the slope of the correlation line is zero, Equation (10) holds, and power is directly proportional to liquid density. In the transition range the effect of density is variable and the value of the exponent m (the slope of the line) in Equation (9) must be evaluated to determine the effect. The same is true for turbulent range operation where the correlation line has a slope other than zero.

Speed Power Relations. Equation (10), applying in the turbulent range, shows that the power is proportional to the cube of the speed when the slope of the power number-Reynolds number curve is zero.

Plots of data show such slopes in the turbulent range under baffled conditions. It is convenient to plot speed versus power directly on logarithmic coordinates, and such lines have a constant slope of ⅓. Since almost all mixing operations in water are at Reynolds numbers between 10^4 and 10^6, it is convenient for design purposes to simplify the general correlation and to use a speed versus power plot as shown in Figure 16. Experimental points are omitted from Figure 16 since they were too numerous to be included. Data have been plotted, however, for all the impellers shown in Table 2 in the turbulent range, and without exception when baffles are used excellent straight-line correlations with the slope of ⅓ were obtained.

Similar lines can be drawn based on the data of Table 6 for the Reynolds number of 10^5. The power number and value of K for Equation (10) is read directly from Table 6, and a single point on the speed-power log-log plot can be computed for a given diameter impeller turning at a chosen speed and for the density and viscosity of the liquid used. This single point can then be extended by drawing a line through this point with a slope of ⅓, and, thus, the whole range of power data for a wide range of speed can be computed accurately.

Since Equation (8) applies for Reynolds numbers less than 10, it is evident that power is a function of the square of the speed in viscous flow conditions.

Impeller speed has an additional effect on power when the effect of the Froude number is significant, or in the transition range where the values of m and n of Equation (10) are not constant. To illustrate this effect, assume a propeller operating in an unbaffled tank where the values in Equation (5) taken from Figure 15 are:

$$N = 120 \text{ rev./min., or } 2 \text{ rev./sec.}$$

$$D = 1 \text{ ft.}$$

$$N_{Re} = 10^4$$

from which

$$m = -0.2 \text{ and } n = -4/18, \text{ or } -0.22$$

then

$$\frac{Pg}{\rho N^3 D^5} = K\left(\frac{D^2 N \rho}{\mu}\right)^{-0.2}\left(\frac{N^2 D}{g}\right)^{-0.22}$$

giving

$$P = \frac{K}{g^{0.78}}\,\rho^{0.8}\mu^{0.2}N^{2.36}D^{4.58}$$

Here power is shown to be affected by the 2.36 power of speed rather than by the cube of the speed. Such equations are not useful, however, as generalizations, because they apply only to particular points in the transition ranges or for unbaffled conditions, or whenever the correlation lines have changing slopes. Since most industrial installations operate under baffled conditions, Equations (8) and (10) are recommended to show the speed-power relations, and Equation (4) should be resorted to for cases where 8 and 10 do not apply.

Impeller Diameter. Impeller diameter appears in Equation (3) in the power number, the Reynolds number and the Froude number. It appears also in the size or boundary ratios, but in these latter it is used essentially as a reference dimension. Limiting consideration of diameter, at this point, to its appearance in the three dimensionless groups (N_P, N_{Re}, and N_{Fr}), it is at once apparent that Equation (10) applies when baffles are used and turbulent conditions exist. Equation (10) shows that power is proportional to the fifth power of the impeller diameter. Table 7 gives sample data for power at 100 rev./min. for flat-blade turbines by which this relation may be checked. Data from this table are plotted in Figure 17. The solid points in the plot are for turbines having different diameters but the same proportion of blade size to diameter; that is, the ratios of turbine diameters to blade lengths and to blade widths were identical, and were as 20 to 5 to 4. A line drawn through these solid points covers a sixfold range of power, and for turbines from 3 to 48 in. in diameter the slope of the line is precisely 1/5, which shows the horsepower to be proportional to the fifth power of impeller diameter.

Since Equation (8) applies to all impellers operating under viscous conditions, it is evident that for Reynolds numbers less than 10 the power is proportional to the cube of impeller diameter.

Linear Dimensions. The linear dimension variables are all shown related to impeller diameter D in Equation (3) in the form of ratios. If all linear dimension ratios are held constant, Equation (3) reduces to Equation (10) and applies to the zero slope portion of the curves of Figure 15 where K for the equation is equal to the ordinate ϕ. If power is affected by a change in one of the linear dimensions (ρ, N, and D, kept constant), the data of Table 6 show that the values of ϕ, and thus of K, are affected. Except for impeller pitch the values of ϕ at Reynolds numbers of 5 and 200 seem to be unaffected by linear dimension changes. The ϕ for 100,000, however, is sensitive to linear dimension change, thus K will vary for such changes. If the functional relationship can be determined, the values of the exponents of Equation (3) may be found.

It is convenient to use the ratios and exponents of Equation (3) to operate on the value of ϕ, or of K in Equation (10) (or Equation (4) if it applies). For example, to calculate the effect of tank diameter T, the value of the exponent t must be known. Then, if T_1 is the tank diameter for which the value of ϕ and K_1 is known and T_2 is a larger diameter for which the value K_2 is desired, K_2 will equal $K_1\ (T_2/D)^t \div (T_1/D)^t$

or

$$K_2 = K_1(T_2/T_1)^t \qquad (11)$$

Other variables may be handled in the same way by operating on a reference value of K as shown.

Effect of Tank Diameter. Flat-blade turbines of from 14 to 48 in. were operated in the 96-in. diameter tank. These were all run 32 in. above the tank bottom and allow a comparison of power required for a given speed with different tank diameter-impeller diameter ratios (T/D), all other size variables being constant. Table 7 shows data for the horsepower at 100 rev./min. for the different diameter turbines. All these turbines had 6 blades. It is found that the power number is essentially constant between T/D ratios of 2.0 to 7.0, and thus

TABLE 6.—SUMMARY OF DATA

Impeller Diameter D in.	Tank Diameter T in.	Ratio T/D	Liquid Depth Ratio H/D	Off Bottom Ratio C/D	Baffle Width $100\,J/T$ % T	Pitch E/D	No. of Blades B	Blade Length Ratio L/D	ϕ at Nre of 5	ϕ at Nre of 200	ϕ at Nre of 100,000
Propeller											
4	8.5	2.12	2.75	1.0	none	1.15	3	....	8.0	0.73	0.19
					8.8				8.0	0.73	0.30
4	13	3.25	3.9	1.0	none	1.15	3	....	8.3	0.73	0.25
					8.3				8.4	0.75	0.32
					10.0				8.4	0.75	0.32
4	13	3.25	3.9	1.0	none	2.0	3	....	9.7	1.26	0.52
					5.6				9.7	1.24	0.86
					10.0				9.7	1.24	1.00
4	18	4.5	4.05	1.0	8.3	1.15	3	....	8.4	0.75	0.23
5	13	2.6	3.12	1.0	5.6	1.02	3	....	8.3	0.75	0.26
					10.0				8.5	0.73	0.30
6	18	3.0	3.0	1.0	none	1.02	3	....	8.3	0.75	0.22
					5.6				8.3	0.75	0.28
					10.0				8.3	0.75	0.32
12	36	3.0	3.0	1.0	8.3	0.98	3	....	8.3	0.77	0.30
					10.0				8.3	0.77	0.32
12	54	4.5	4.5	1.0	none	0.98	3	....	8.3	0.75	0.29
					8.3				8.3	0.75	0.34
					10.0				8.3	0.75	0.35
18	54	3.0	3.0	1.0	none	1.03	3	....	....	....	0.26
					8.3				....	....	0.32
					10.0				....	....	0.32
20	54	2.7	2.7	1.0	none	1.10	3	....	8.2	7.5	0.21
					10.0				8.2	7.5	0.28
					14.7				8.2	7.5	0.34
20	90	4.5	4.5	1.0	10.0	0.99	3	....	....	....	0.36
					10.0	1.50	..	....	....	....	0.62
					10.0	2.50	..	....	....	....	1.35
Propeller Off-Centered											
4	13	3.25	2.9	1.0	...	1.15	3	....	....	0.73	0.33
4	13	3.25	3.9	1.0	....	2.00	3	....	....	....	1.00
6	18	3.0	3.0	1.0	....	1.03	3	....	8.3	0.77	0.32
Flat Blade Turbine											
3	8.5	2.83	3.7	1.3	none	....	6	4.0	14.2	3.5	1.1
					8.8				14.4	3.7	5.5
					10.0				14.4	3.7	5.5
					17.7				14.2	3.5	5.9
3	13	4.33	5.2	1.7	none	....	6	4.0	14.9	3.7	1.15
					5.6				14.9	3.9	5.7
					10.0				14.9	3.7	6.2
3	18	6.0	7.4	1.7	none	....	6	4.0	15.1	3.9	1.32
					5.6				15.1	3.5	4.8
					8.3				15.1	3.9	6.0
					10.0				15.1	3.7	6.2
4	8.5	2.12	2.75	1.0	none	....	6	4.0	13.3	3.5	1.26
					8.8				13.3	3.5	5.5
					10.0				13.3	3.7	6.21
					17.7				13.3	3.7	6.4
4	13	3.25	3.9	1.2	none	....	6	4.0	14.2	3.7	1.33
					8.3				14.2	3.5	5.7
					10.0				14.2	3.5	6.0
4	18	4.5	4.05	1.2	none	....	6	4.0	14.2	3.5	1.42
					5.6				14.2	3.5	5.1
					8.3				14.2	3.5	5.8
					10.0				14.2	3.5	6.2
5	8.5	1.7	2.2	0.8	none	....	6	4.0	14.2	3.7	1.28
					8.8				14.2	3.7	6.2
					10.0				14.1	3.7	6.4
5	13	2.6	3.12	1.0	none	....	6	4.0	13.9	3.7	1.26
					8.3				13.9	3.4	6.0
					10.0				13.9	3.5	6.4
5	18	3.6	3.24	1.0	none	....	6	4.0	14.2	3.5	1.24
					8.3				14.2	3.5	6.2
					10.0				14.2	3.5	6.4
6	8.5	1.41	1.83	0.5	none	....	6	4.0	15.1	3.7	0.75
					8.8				15.1	3.7	6.9
					10.0				15.1	3.7	7.1
6	13	2.16	2.6	1.0	none	....	6	4.0	14.6	3.7	1.06
					8.3				14.6	3.7	5.9
					10.0				14.6	3.7	6.6
6	18	3.0	3.0	1.0	none	....	6	4.0	14.2	3.7	1.15
					5.6				14.2	3.7	4.1
					8.3				14.2	3.7	6.0
					10.0				14.2	3.7	6.2
6	18	3.0	3.0	1.0	8.3	....	2	4.0	....	....	3.3
					10.0				....	....	3.4
6	18	3.0	3.0	1.0	8.3	....	4	4.0	....	....	4.3
					10.0				....	....	4.4
6	18	3.0	3.0	1.0	8.3	....	5	4.0	....	....	5.4
					10.0				....	....	5.4
6	18	3.0	3.0	1.0	8.3	....	8	4.0	....	....	7.8
					10.0				....	....	7.8
6	18	3.0	3.0	1.0	8.3	....	12	4.0	....	....	9.9
					10.0				....	....	10.0
8	36	4.5	4.5	1.5	8.3	....	6	4.0	....	....	6.4
10	30	3.6	3.0	1.2	8.3	....	6	3.33	....	....	6.2
12	36	3.0	3.0	1.0	8.3	....	6	4.0	....	....	6.0
					10.0				....	....	6.0

TABLE 6.—(*Continued*)

Impeller Diameter D in.	Tank Diameter T in.	Ratio T/D	Liquid Depth Ratio H/D	Off Bottom Ratio C/D	Baffle Width $\frac{100\,J}{T}$ % T	Pitch S/D	No. of Blades B	Blade Length Ratio L/D	ϕ at N_{Re} of 5	ϕ at N_{Re} of 200	ϕ at N_{Re} of 100,000
14	96	6.85	6.8	2.3	8.3	....	6	3.5	....	....	6.4
16	54	3.37	3.4	1.0	none	....	6	4.0	13.9	3.7	1.06
					8.3				13.9	3.7	5.7
					10.0				13.9	3.7	6.0
					15.0				13.9	3.7	6.2
16	96	6.0	6.0	2.0	8.3	....	6	4.0	....	....	6.4
18	54	3.0	3.0	1.0	none	....	3	3.6	9.8	3.5	0.35
					8.3				9.8	3.5	3.3
					10.0				9.8	3.5	3.4
					15.0				9.8	3.7	3.7
18	54	3.0	3.0	1.0	10.0	....	4	3.6	....	....	4.6
18	54	3.0	3.0	1.0	10.0	....	5	3.6	....	....	5.3
18	54	3.0	3.0	1.0	none	....	6	3.6	14.2	3.7	1.06
					8.3				14.2	3.7	6.4
					10.0				14.2	3.7	6.2
					15.0				14.4	3.7	6.4
18	54	3.0	3.0	1.0	10.0	....	7	3.6	....	....	6.9
18	54	3.0	3.0	1.0	none	....	8	3.6	14.4	3.7	1.15
					8.3				14.6	3.7	7.5
					10.0				14.6	3.7	7.8
18	54	3.0	3.0	1.0	none	....	10	3.6	14.9	3.5	1.10
					8.3				14.9	3.5	8.2
					10.0				14.4	3.5	8.7
18	96	5.34	5.3	1.8	8.3	....	6	3.6	....	....	6.2
20	54	2.7	3.0	0.9	none	....	6	4.0	14.4	....	1.06
					8.3				14.4	....	6.0
					10.0				14.4	....	6.0
20	96	4.8	4.8	1.6	10.0	....	6	4.0	....	....	6.0
22	96	4.36	4.4	1.5	10.0	....	6	4.4	....	....	6.4
24	54	2.33	2.3	0.7	none	....	6	4.0	13.9	....	1.15
					8.3				13.9	....	6.2
					10.0				13.9	....	6.2
24	96	4.0	4.0	1.3	10.0	....	6	4.0	....	....	6.4
26	96	3.7	3.7	1.2	10.0	....	6	3.7	....	....	6.2
28	96	3.43	3.4	1.1	10.0	....	6	3.43	....	....	6.4
30	96	3.2	3.2	1.1	10.0	....	6	3.2	....	....	6.0
32	96	3.0	3.0	1.0	10.0	....	6	3.0	....	....	6.2
34	96	2.82	2.8	1.0	10.0	....	6	2.82	....	....	6.2
36	96	2.67	2.7	0.9	10.0	....	6	2.67	....	....	6.4
42	96	2.29	2.3	0.8	10.0	....	6	2.29	....	....	6.2
48	96	2.0	2.0	0.7	10.0	....	6	2.0	....	....	6.2
Turbine, Six Curved Blades											
4	8.5	2.12	2.75	1.0	8.8	....	6	4.0	13.7	3.40	4.8
					10.0				15.7	3.50	4.6
4	13	3.25	3.0	1.0	8.3	....	6	4.0	17.9	3.40	4.6
					10.0				13.9	3.40	4.8
4	18	4.5	4.0	1.0	8.3	....	6	4.0	13.9	3.40	4.3
					10.0				13.9	3.40	4.8
Turbine, Six Arrowhead Blades (Disperser)											
4	8.5	2.12	2.75	1.0	8.8	....	6	4.0	14.2	3.45	2.7
					10.0				14.2	3.45	3.9
5	13	3.25	3.0	1.0	none	....	6	4.0	14.9	3.50	....
					8.3				14.9	3.40	5.7
					10.0				14.9	3.45	3.9
5	13	2.6	3.0	1.0	8.3	....	6	4.0	14.5	3.45	2.8
6	18	3.0	3.0	1.0	8.3	....	6	4.0	14.2	3.40	3.9
18	54	3.0	3.0	1.0	none	....	6	4.0	14.2	3.40	0.71
					8.3				14.2	3.45	4.13
					10.0				14.2	3.45	4.4
Fan Turbine						Angle		L/W			
4	6.5	2.12	2.75	1.0	8.8	45°	6	2.3	12.8	2.30	1.60
					10.0				12.8	2.50	1.63
5	13	3.25	3.0	1.0	5.6	45°	6	2.3	13.0	2.30	1.38
					10.0				13.0	2.30	1.43
4	18	4.5	4.0	1.2	8.3	45°	6	2.3	12.8	2.50	1.51
					10.0				12.8	2.30	1.56
18	54	3.0	3.0	1.0	none	45°	8	3.4	14.2	2.18	0.60
					8.3				14.2	2.50	1.69
					10.0				14.2	2.50	1.65
Shrouded Six Curved-Blade Turbine											
4	8.5	2.12	2.75	1.0	10.0	....	6	....	19.5	2.65	1.06
4	13	3.25	3.0	1.0	10.0	....	6	....	19.5	2.50	1.10
4	18	4.5	4.0	1.2	8.3	....	6	....	17.7	2.65	1.03
4	13	3.25	3.0	1.0	stator ring	....	6	....	24.5	2.50	1.12
Paddles, Two-Blade											
4	8.5	2.12	2.75	1.0	8.8	....	2	2	7.3	1.56	1.95
4	13	3.25	3.0	1.0	8.3	....	2	2	7.3	1.56	1.65
4	18	4.5	4.0	1.2	8.3	....	2	2	7.1	1.56	1.77
18	54	3.0	3.0	1.0	8.3	....	2	3	7.3	1.60	1.63
					10.0				7.3	1.59	1.69
24	54	2.25	2.25	0.75	none	....	2	3	7.3	1.42	0.46
					8.3				7.3	1.56	1.77
					10.0				7.3	1.56	1.95
					15.0				7.3	1.56	2.10
24	96	2.5	2.5	1.3	8.3	....	2	3	7.3	1.56	1.95
42	96	2.3	2.3	0.8	8.3	....	2	3	7.3	1.56	2.10

the power is not a function of the T/D ratio. It is recommended that the value of the exponent t for all turbines where Equation (10) applies be zero for T/D ratios between 2.0 and 7.0.

Data from Figure 13 illustrate the effect of tank diameter for propellers operating without baffles. The exponent t is 0.91 for values of T/D between 2.7 and 4.5 at Reynolds number of 100,000. Other data computable from Table 6 show that the value t should be zero for propellers operating in baffled conditions.

Effect of Liquid Depth. In many cases the liquid depth H was equal to tank diameter T, and $H/D = 3$. H/D ratios were varied from 2 to 4.8 in the 96-in. tank and no effect was found. However the ratio T/D was varied at the same time. Until further data are available it is recommended for propellers or turbines, that the exponent h in Equation (3) be zero for H/D ratios of from 2 to 4.

Impeller Height Off Bottom. The ratio of height of impeller above tank bottom to impeller diameter (C/D) was varied but no data are reported where H/D and T/D were held constant at the same time. Most of the data were taken for constant liquid depth and height of impeller off bottom. Under these conditions the exponent c has a value of zero between C/D limits of 0.7 to 1.6. However, it is known that for constant liquid depth, tank diameter and impeller diameter, the distance C and thus the ratio C/D has a marked effect on power; accordingly, more data are needed to evaluate the exponent c under such conditions.

Number of Baffles. Data are not shown here, for the effect of number of baffles, R, but data previously reported in the literature (*2*) show that the exponential value r for $(R/4)$ in Equation (3) is 0.43 for from 2 to 4 baffles.

Effect of Baffle Width. Baffle width J is the dimension of the baffle along the diameter of the mixing tank. Table 6 shows baffle width in terms of per cent tank diameter $\frac{100J}{T}$ and values of the power number can be found for the various baffle sizes in the same table. Baffle widths of 1/10 and 1/12 tank diameter are commonly used in industrial operations. The effect of J is illustrated graphically in Figure 14. There is no noticeable effect of baffle width on power when operation is in the viscous range, or below N_{Re} of about 300. Above this Reynolds number, and in the turbulent range, the baffle width exerts an effect on power requirements. The value of the exponent j for use with the ratio J/D for Equation (3) is 0.30 for J/D ratios between 0.15 and 0.5. This corresponds to baffles from 5 to 17% of tank diameter.

Effect of Pitch of Impeller Blades. The pitch S of a propeller is a measure of the angle of the propeller blades. To produce uniform velocity of flow, the blade angle of a marine-type propeller (Fig. 2) increases (with respect to axis of rotation) as the radius is increased. Such a relation gives uniform pitch, and pitch can be stated in terms of "advance" of fluid. Thus, the pitch of a propeller is the distance liquid is displaced along the impeller axis at zero slip when the propeller is turned one revolution. A square pitch propeller is one whose pitch is equal to its diameter, or $S/D = 1$.

The effect of propeller pitch for operation without baffles is compared by curves 3 and 5 in Figure 12. Propeller pitch affects the shape and position of the curves. In the viscous range the shape is the same and the power is about seven per cent higher for the higher pitch propeller. Above a Reynolds number of about 20 the curves separate increasingly with an increase in the Reynolds number. The higher pitch propeller requires more power for operation at the same speed than a low pitch propeller. The pitch variations studied may be compared in detail in Table 6 by the values of N_P at corresponding Reynolds numbers.

When baffles are present, the lower pitch propellers have longer transition ranges and the flat section of the curve where Equation (10) applies occurs over a smaller range at high Reynolds numbers. For example, for a pitch of two (curve 6, Fig. 12 and curve 4, Fig. 15) Equation (10) applies for Reynolds numbers above 5000, whereas for a propeller pitch of one (curve 2, Fig. 15) Equation (10) applies for Reynolds numbers above 20,000.

The effect of pitch of a 20-in. propeller on the power requirement in baffled conditions is given in Table 8. The pitch-diameter ratio S/D varied between 0.99 and 2.50. The blade area is approximately constant, and the comparison is made at a propeller speed of 420 rev./min. The value of s for the ratio S/D in Equation (3) is 1.7 for these propellers.

For fan turbines the pitch is stated as the angle which the flat blades of the turbine make with the axis of rotation. The fan turbines used had flat blades tilted to a 45° angle with the axis of rotation. These turbines operated so that displacement was downward. No variation of pitch was made; hence, the value of s for fan turbines was not found.

Effect of Number of Blades. The flat-blade turbines were made with from 3 to 12 blades and various blade sizes were used, as shown in Table 6 in the column L/D. Data are sufficient to construct speed power plots as shown in Figure 16, and from such plots the effect of number of blades on power can be determined directly for any desired speed. Data of power at a given speed vs. number of blades B were plotted on logarithmic coordinates and were most conveniently correlated by two straight lines intersecting near $B = 6$. Therefore, it is convenient to use the 6-blade turbine as a basis and to use the ratio $B/6$. For less than 6 blades the exponent b_a is used and for more than 6 blades the exponent b_b is used. Results for turbines between 6-in. and 34-in. diameter are: $b_a = 0.8$ for 6 blades and less, and $b_b = 0.7$ for 8 to 12 blades.

The few experiments with fan turbines were for turbines with 4 and 8 blades. The value of b_a of 0.8 for the flat-blade turbines fits the data for these two fan turbines also.

Effect of Length and Width of Blades. Blade length L is the dimension in radial direction whereas blade width W is the dimension parallel to the axis of impeller rotation. (*See* Fig. 8.) The blades of curved-blade and arrowhead-blade turbines were sized such that their projections along a radius were identical to the flat-blade dimensions. In all cases shown here the ratio of blade length to blade width (L/W) was constant at 1.25. Thus the independent effects of L and W were not evaluated. The effect of variation of blade length for a constant value of 1.25 for the ratio of L/W can be made, however, and a value of 1 for use in the $(L/D)^l$ ratio of Equation (3) under such conditions may be noted as l'. l' is found to be 1.5 for flat-blade turbines.

Data are tabulated in Table 7* showing the values of T/D and L/D and corresponding power for flat-blade turbine diameters from 3 to 48 in. As noted above, the ratio T/D has no effect under the conditions studied. On this basis the power data can be corrected for the L/D effect for constant L/W ratio. The table shows power at 100 rev./min. as read from experimental curves and

* See Note on page 467.

data. Since many of the turbines were fit with blades where $L/D = 1/4$, or 0.25, this condition is used for reference. (Such data are plotted as solid points in Fig. 17.) Since P for $(L/D)^P$ is 1.5, the value $\left(\frac{0.25}{L/D}\right)^{1.5}$ is the correction factor to calculate values of power to the basis of $L/D = 1/4$, the reference condition for dimensional similarity. Such values are given in the table followed by the power corrected to the $L/D = 1/4$. This value of power at 100 rev./min. was then used to compute the power number (labeled calculated), and this column shows the good agreement of the data, in that all values are substantially equal to the over-all average of 6.3 of the last column.

It is to be noted further that the calculated values (corrected to $L/D = 1/4$) of the turbine sizes, which are plotted by open circles in Figure 17, would fall on the line passing through the solid points. The lines connecting the solid and open points are for different-sized turbines, but each individual line connects turbines which are made with the same actual blade size. For example: the 18-, 20-, and 22-in. turbines have the same-sized blades; thus, the 18-in. turbine has a larger blade and the 22-in. turbine a smaller blade than the reference ratio of $L/D = 1/4$ on the 20-in. turbine.

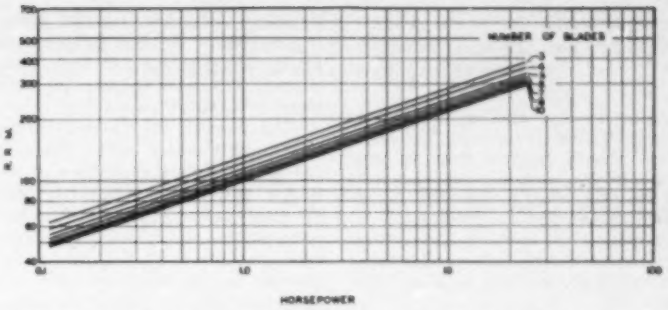

Fig. 16. Speed Power Relations for An 18-inch Flat Blade Turbine.

Summary

Equations (3) and (5) can be used to characterize mixing impellers, and can be used graphically as in Figure 15 for comparative purposes.

Impellers operating in vertical cylindrical flat-bottomed tanks, one impeller diameter off bottom, shaft on vertical centerline (except the off-centered propeller), tank diameter three times impeller diameter, and liquid depth equal to tank diameter, have characteristics as shown in Figure 15. The following values of ϕ in Table 9 at Reynolds numbers of 5, 200, and 100,000 are for the corresponding curves of Figure 15.

Equation (10),

$$P = \frac{K}{g}\rho N^3 D^5$$

applies to any impeller when operating at high Reynolds numbers where the correlation curve slope is zero. Such is the case for operation with baffles (or their equivalent in off-centering). The value of K is equal to the value of ϕ at 100,000 in the list above for the particular impeller and environment, and applies over the Reynolds number range where the slope is zero.

If variables other than ρ, N, and D are to be accounted for, the value of ϕ, and thus of K, is modified by using a relation like that of Equation (11), which is equivalent to the use of Equation (3). Appropriate values of the exponents are summarized for the propeller and the flat-blade turbine in Table 10.

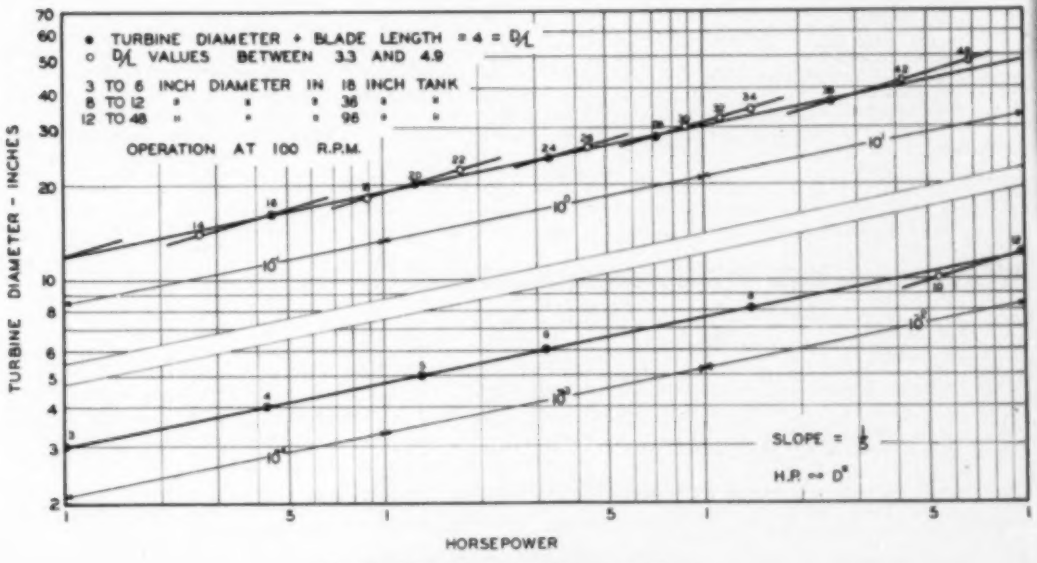
TURBINE DIAMETER + BLADE LENGTH = 4 = D/L
D/L VALUES BETWEEN 3.3 AND 4.9
3 TO 6 INCH DIAMETER IN 18 INCH TANK
6 TO 12 " " " 36 " "
12 TO 48 " " " 96 " "
OPERATION AT 100 R.P.M.
SLOPE = 1/5
H.P. ∝ D^5
TURBINE DIAMETER - INCHES
HORSEPOWER

Fig. 17. Effect of Turbine Diameter on Power.

Equation (8),

$$P = \frac{K}{g}\mu N^2 D^3$$

applies to any impeller operating at Reynolds numbers below 10. The values of K may be computed from the value of ϕ at N_{Re} of 5 and such values of ϕ are summarized in Table 9. The dimension variables have little effect on the value of K in this equation. Propeller pitch was the only variable found to have a marked effect on K of Equation (8).

For operation with baffles in the transition range where neither Equations (8) and (10) apply, Equation (5) may be evaluated, but since the slope of the Reynolds number-power number curves is not constant, the resulting equations having fractional exponents are of little practical importance because they apply to one limited condition only.

When impellers are operated without baffles, and a vortex results, Equation (4) applies and the exponent s of the Froude number is a function of the Reynolds number, and probably of impeller position also. Only at high Reynolds numbers is the slope of the Reynolds number correlation plot constant, hence there is little to be gained by simplifying Equation (4). At high Reynolds number operation the characteristics approach Equation (10) as a limit.

TABLE 8.—EFFECT OF PITCH ON PROPELLER PERFORMANCE, 10% BAFFLES

Propeller Diameter D in.	Pitch S in.	$\frac{S}{D}$	H.P. at 420 rev./min.	Blade Area sq.in.
20	19.8	0.99	4.75	169
20	21.9	1.10	5.45	159
20	30.0	1.50	10.2	172
20	50.0	2.50	21.2	178

TABLE 9.—VALUES CORRESPONDING TO FIGURE 15

Curve	Impeller	ϕ at Reynolds Number of 5	200	100,000
1	*Propeller, square pitch	8.3	0.75	0.29
2	Propeller, square pitch	8.4	0.75	0.32
3	*Propeller, pitch of 2	8.7	1.25	0.52
4	Propeller, pitch of 2	8.7	1.25	1.00
5	*Turbine, flat blade	14.2	3.7	3.15
6	Turbine, flat blade	14.2	3.7	6.30
7	Turbine, curved blade	14.0	3.4	4.80
8	Turbine, arrowhead	14.2	3.4	4.00
9	Fan turbine	14.0	2.5	1.65
10	Flat paddle	7.3	1.85	1.70
11	Shrouded turbine	19.5	2.5	1.08
12	Shrouded turbine, stator	34.5	2.6	1.12

* No baffles.

TABLE 10.—VALUES OF EXPONENTS FOR EQUATION 5 WHEN THE EXPONENT m OF THE REYNOLDS NUMBER IS ZERO. VALUE OF THE FROUDE EXPONENT IS ALSO ZERO

Ratio	Propeller Exponent	Propeller Range of Ratio	Turbine, Flat Blade Exponent	Turbine, Flat Blade Range of Ratio
T/D	$t = 0$	2.5 to 6	$t = 0$	2 to 7
B/D	$b = 0$	2 to 4	$b = 0$	2 to 4
C/D			$c = 0$	0.7 to 1.6
S/D	$s = 1.7$	1 to 2.5		when C is constant
L/D			$l = 1.5$	0.18 to 3
				when $L/W = 1.5$
J/D			$j = 0.3$	0.1 to 0.5
$H/6$			$h_0 = 0.8$	2 to 6
			$h_0 = 0.7$	8 to 12
$H/4$			$r = 0.4$	2 to 4

Acknowledgment

This work was carried on in the experimental laboratories of the Mixing Equipment Co., Rochester, as part of a continuing program of research on mixing and agitation. The advice, encouragement, and assistance of E. S. Bissell and F. D. Miller are greatly appreciated by the authors.

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(Presented at Fortieth Annual Meeting, Detroit, Mich.)

(The End)

New fields are opening to chemical engineers and the authors, in this article, tell about one of them—the control of drilling mud in petroleum exploration . . . efforts of the chemical engineer and the drilling engineer must be combined for success in overcoming any specific drilling problem.

MUD CONTROL AND DESIGN

VICTOR V. HORNER and W. B. KIMBRELL

National Lead Company, Tulsa, Oklahoma

IN the past few years, drilling fluids have become a major tool in the advancement of drilling technique and have opened an engineering field of vast importance to the oil industry. It has been recognized and well established that the inflow of gas or fluids and loss of drilling fluid are controllable by the correct application of hydrostatic principles and control of mud friction factors; that transportation of cuttings is a matter of carrying power expressed through viscosity and gelation properties with consideration given to proper flow characteristics; shale caving or sloughing is greatly influenced by the degree of water-wetting of the shales; the filtration cake deposited on the wall of the hole is related to mud quality and is a common source of trouble subject to correction; protection of permeability in reservoir zones is related to the chemical make-up of a mud and is a factor in initial production rate; abrasive and corrosive actions of a mud are of sufficient importance to be controlled; value of electric logging data is dependent upon the chemical character of a mud. These functions cover a broad field, some are interrelated, but as a whole, they are independent and each is sufficiently important and complex to justify specialized study.

Weight Control. High specific gravity weight minerals (barite) have long been employed as an additive to drilling fluid for increasing mud density in the control of inflow of gas or fluids from the drilled formations. Mud weights in the 15 to 19 lb./gal. range are in common use with today's deeper drilling, and present a complex problem in their design and control. Muds in this weight range must remain fluid with a minimum viscosity to allow the removal of entrained gas.

In preparing a weighted mud, barium sulfate, with a specific gravity of 4.3, is added to a prepared base mud, or to a base mud already in use in the drilling operation, and usually containing low specific gravity suspending material. As the weighting material is added for increased fluid density, the total effective volume percentage of solids increases. Dependent upon the effective per cent volume of low specific gravity material originally in the base mud, the amount of barite addition is, therefore, limited by resultant viscosity and gel strength. The same effect is realized when a weighted mud with satisfactory viscosity and gel strength properties is in use in drilling formations that add to the low specific gravity concentration; viscosity and gel strength increases would be expected.

Considering practical operating limits of viscosity and gelation, as the weight required for a specific mud increases, or addition of low specific gravity solids occurs through drilling, the effective volume percentage of low specific gravity suspended material must be reduced. This may be done (1) by dilution and addition of barite; (2) by dehydrating the low specific gravity particles, or (3) by employing a higher specific gravity solution phase.

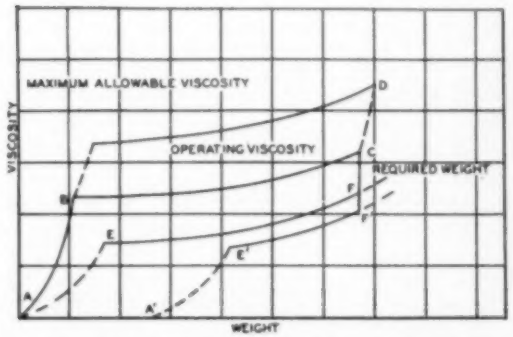

Fig. 1. Weight-Viscosity Relationship—Weighted Mud.

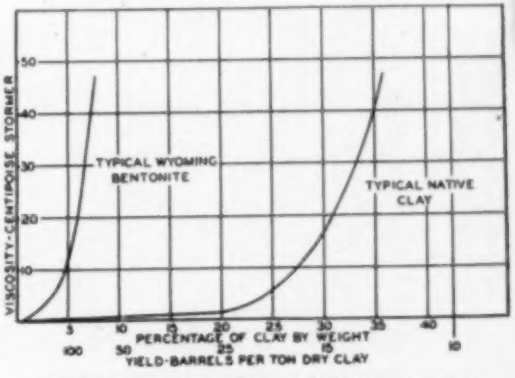

Fig. 2. Viscosity-Percentage of Solids Relationship —Fresh Water.

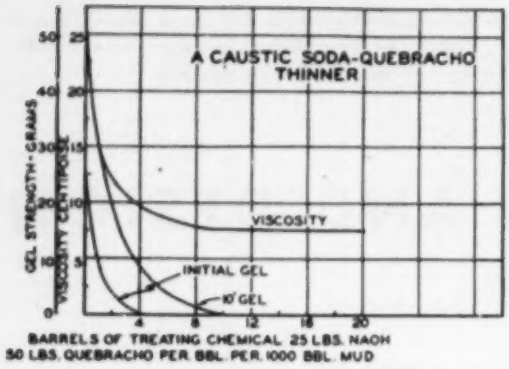
A CAUSTIC SODA-QUEBRACHO THINNER
GEL STRENGTH - GRAMS
VISCOSITY - CENTIPOISE
VISCOSITY
INITIAL GEL
10' GEL
BARRELS OF TREATING CHEMICAL 25 LBS. NAOH
50 LBS. QUEBRACHO PER BBL. PER 1000 BBL. MUD

Fig. 3. Viscosity Gel Strength Reduction.
Native fresh water mud.

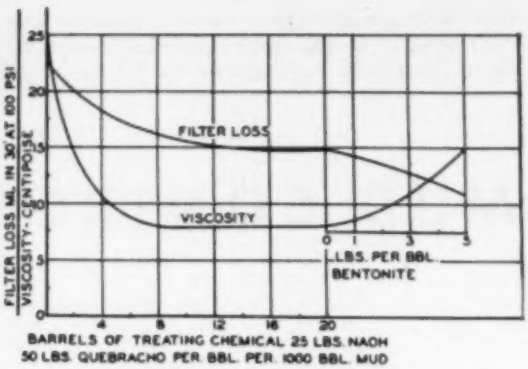
FILTER LOSS ML. IN 30' AT 100 PSI
VISCOSITY - CENTIPOISE
FILTER LOSS
VISCOSITY
LBS. PER BBL. BENTONITE
BARRELS OF TREATING CHEMICAL 25 LBS. NAOH
50 LBS. QUEBRACHO PER BBL. PER 1000 BBL. MUD

Fig. 4. Filter Loss Reduction.
Native fresh water mud thinner plus bentonite.

Figure 1 is a hypothetical representation of the viscosity-weight relationship of weighted muds showing the governing limitations and control approach. The line AB represents a hydrated or semihydrated clay added to fresh water as a suspending agent for the addition of barite along line B to C. The point C represents a mud designed for a required weight at operating viscosity. As low specific gravity solids are incorporated in the weighted mud along CD through drilling progress, the tendency of the mud is to increase slightly in weight and to increase in viscosity until the maximum allowable viscosity for release of entrained gas or fluid pumpability is reached at D. To control the viscosity below the maximum allowable, this mud may be diluted with fresh water to reduce the percentage of low specific gravity solids with addition of barites, if necessary, to maintain the required weight. A second control method would be the chemical dehydration of the base clay AB or any hydrated clay added through drilling, CD, with the yield of these low specific gravity materials depressed to assume the position AE, which, together with the assistance of the high specific gravity weighting material along EF, would provide a reduced viscosity mud at the required weight at F. The third design or control method would be the use of a higher specific gravity liquid phase, such as saturated salt water. In this case the dehydrated base clay would assume the position of $A'E'$ when mixed with the higher specific gravity liquid phase, and with the further addition of barites along $E'F'$ a mud would be provided with the required weight of a low viscosity.

Considering the limitation of viscosity, it may be noted that much higher weight muds may be prepared and controlled through the latter two design methods. The high weight muds in use today, viz., muds in the range of 15 to 19 lb./gal., are mostly of these types.

Control of highly weighted muds generally involves the matter of circulation loss where the mud weight must be controlled between the maximum permitted break-down weight and the minimum required to overcome the formation pressures at hand. This condition generally places the weight at a fixed value with little control tolerance. An understanding of the viscosity-weight relationship of weighted muds is particularly important in the design and control of such critical cases.

Viscosity and Gelation Control. Proper transportation of cuttings depends on the "carrying power" of the drilling mud to lift bit cuttings to the surface and yet allow the finer cuttings, not removed by the shale shaker, to settle in the surface pits. Viscosity and gelation control are related to the mechanical drilling operations where annular velocity, drilling rate, and mechanical hole erosion must be considered.

Because of its great ability to swell in water, bentonite has been the most widely used viscosity builder. Where viscosity is required in the design or control of a fresh water drilling mud, the high yield (expressed as the barrels

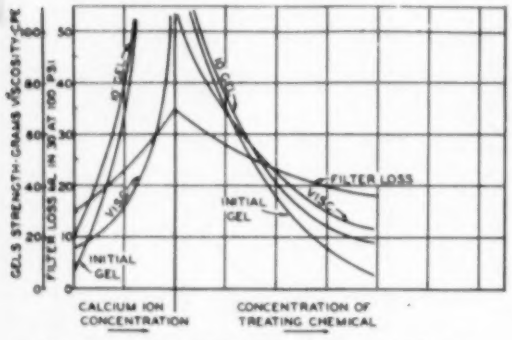

Fig. 5. Effect of Low Calcium Ion Concentration on Mud Characteristics.

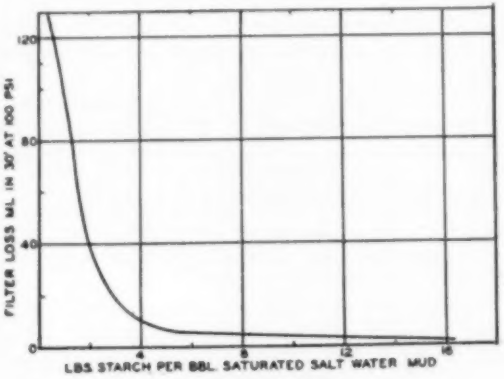

Fig. 6. Filter Loss Reduction.
Starch in saturated salt water mud.

of 15 cp. mud/ton of clay) of Wyoming bentonite makes the material particularly adaptable for this purpose (Fig. 2). Other special clays have been developed and are in use for providing viscosity and gel strength in saline solutions.

Generally, improvement of flow characteristics through reduction of viscosity and gel strengths in fresh water-bentonite muds commands greater attention than increasing these values. Increases in viscosity and gel strengths due to hydration of clays from bit cuttings and hole erosion caused by drill pipe movement are common problems. Uses of water, tanstuff and the polyphosphates to reduce viscosity and gel strengths are control methods in common use. Figure 3 shows the action of a chemical thinner on a typical native fresh water bentonite mud.

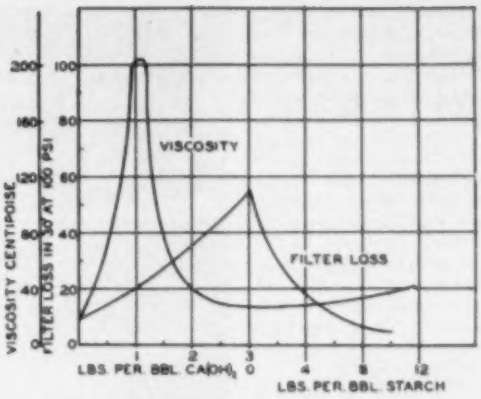

Fig. 7. Characteristics of Lime-Converted Mud.

Control of Filtration Properties. The factor of water wettable shales involves control over the filtration properties, and development has depended upon the application of knowledge on colloidal suspensions. To minimize the filtration rate of a drilling mud requires consideration as to the type of colloidal material, colloidal particle-size distribution, the degree of dispersion and the concentration of the colloid used. Common sources of colloidal particles are from clays, bentonites, starch and other organic colloids.

One method of control involves the use of chemical mud thinners such as some of the tannin compounds and complex phosphates. They have been effective in reducing the viscosity and gel strengths of muds to permit much higher concentration of colloidal particles for a given viscosity, and in controlling flow characteristics and filter loss in fresh water, bentonite-type muds. Figure 4 illustrates the effect of concentrating colloidal particles through the thinning action of caustic soda-quebracho and addition of bentonite on water loss reduction of a fresh water native mud.

Colloidal particles supplied by bentonite and other clays are chemically active, and their behavior is influenced by chemical contamination; the multivalent cations have severest effect. The basis of chemical control of contaminants affecting viscosity, gel strength, and filter-loss characteristics involves reactions where the multivalent cations are converted into an insoluble form and replaced by a single valent cation, generally sodium. This type treatment will minimize the flocculating forces and render the mud more fluid with a given concentration of colloidal particles. Figure 5 depicts the effect of low calcium ion concentration on mud characteristics and the restoration of desirable properties by removal of the calcium ion through precipitation. It is not the intent of these curves to cover the range of contaminate concentration and treatment, but rather to illustrate the effect of the presence of the multivalent cation calcium, in low concentrations, on mud properties. Control of such contamination can be effected by the use of sodium bicarbonate in the case of cement, by the use of sodium carbonate or barium carbonate for anhydrite. Regarding the latter, use of soda ash is limited by the concentration of sodium sulfate formed by the reaction, which can, in high concentrations, prove detrimental to most muds. Heavy anhydrite contamination is effectively treated with barium carbonate, which removes calcium sulfate in its entirety.

More recently, attention has been given to special types of colloidal materials for control of mud filtration properties. It has been found that extremely low filter-loss control depends upon maintaining a percentage of the colloidal material in the lower-size range, and that a pliable-type particle is desirable. The starch particle has been used effectively for this purpose and has afforded a means of producing extremely low filter

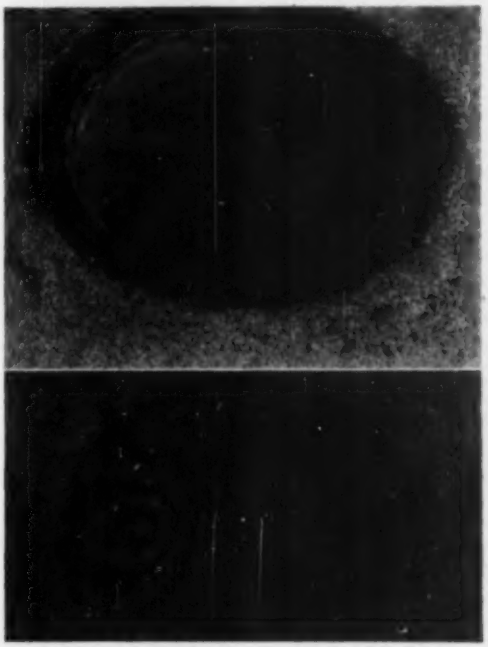

Fig. 8 (above). Low Filter Loss Wall Cake.
Fig. 8a (below). High Filter Loss Wall Cake.

rates. A sterile condition must be provided through use of bactericides, high salinity or high alkalinity. Starch is also extremely useful in that it is unaffected by high chemical concentrations. As a result, low filter-loss muds can be produced under condition of saturated salt (Fig. 6). The synthetic product, sodium carboxy-methyl cellulose, has similar characteristics and is finding application along the same line. In many applications this cellulose derivative has an even greater weight efficiency than commercially prepared starch in water loss reduction, and in addition presents little fermentation hazard. These advantages are to some extent offset, however, by a higher price per unit weight.

Chemically dehydrating the clay particle in a conventional water-clay mud by the use of slacked lime allows the preparation of a stable mud having a wide application. In converting to a mud of this type, caustic soda and quebracho along with any necessary water dilution, are usually employed to assist in raising the alkalinity and to control viscosity and gel-strength increases. The magnitude of viscosity increase during the dehydration process depends mainly on the concentration of hydrated clays in the original mud. Starch is used to reduce filter loss and the resulting mud is a stable composition of starch and nonhydrated solids in a calcium saturated high pH solution. Such muds are particularly adaptable where high weights are required, are not affected adversely by chemical contamination, and through proper maintenance are stable in regard to weight, viscosity and gel strength. Figure 7 illustrates the change in mud characteristics for a lime-converted mud.

A factor related to mud quality and filtration properties of a drilling fluid is the thickness of the filter cake deposited on the wall of the hole. This filter cake is usually proportional to the filter loss for a given mud. Figure 8 and 8a are visual representations comparing the effective diameter of a hole in sand in which a low filter-loss mud has been circulated, and one in which high filter-loss mud has been circulated. The high filter-loss mud reduced the 8¾-in. diameter to 6¾-in. and illustrates the importance of minimizing cake thickness from the standpoint of sticking drill pipe and testing tools.

Where formation porosity and permeability are great enough to permit a partial or complete loss of drilling mud to the formation, bridging and plugging materials of a fibrous or flaky nature are incorporated in the mud. Figure 9 illustrates the plugging action of mud ladened with several such materials. Figure 10 shows a low pressure filter press.

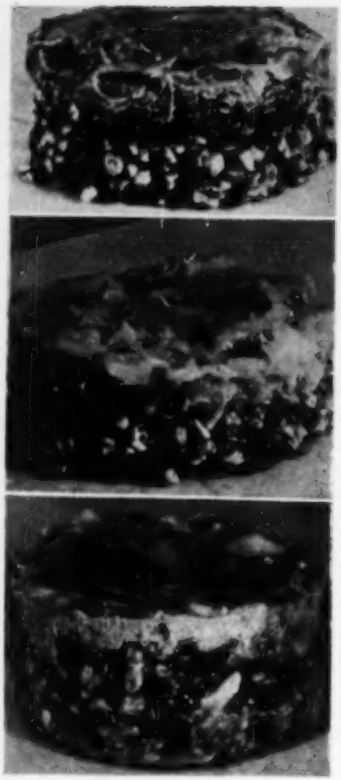

Fig. 9. Loss of Circulation Materials. Top, Fibrous Material. Center, Cellophane Foil. Bottom, Mica.

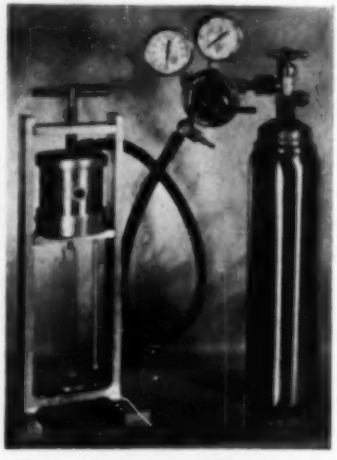

Fig. 10. Low Pressure Filter Press.

Other Items of Control. Protection of permeability in reservoir zones may be related to the chemical composition of a mud and may be a factor in initial production rates. This thought has led to the use of extremely low filtrate freshwater muds, oil-base muds and oil-emulsion muds for well completions. Use of limed or salt-water muds, or muds so treated that the filtrate would duplicate the chemical composition of formation interstitial water, is being tried.

Abrasive and corrosive action of drilling fluids is of sufficient importance to be controlled. Gel-strength reduction through chemical treatment permits the dropping of abrasive sand cuttings in surface-settling ditches and tanks. Sodium chromate and sodium nitrite are being used for retarding the corrosive effect of some drilling muds on drill pipe. A maintained concentration of 2000 p.p.m. of either of these salts in the drilling mud has been found adequate to arrest any observable corrosion.

Interpretation of electric logging data is influenced by the effect of the chemicals in the mud upon the resistivity of the mud. It is most advantageous for the sake of correlative interpretation of electric log data for mud resistivity to be within a suitable range.

Control Instruments. As the drilling mud engineer recognized the importance of drilling mud design and control to the complete drilling operation, he developed instruments for measuring these properties better to prepare a basis for analytical study. The mud hydrometer or balance was devised for density measurements; the Marsh Funnel and Stormer Viscosimeter are used for viscosity and gel-strength measurements; the Baroid Low and High Pressure Filter-Press Units were designed for evaluating filter-loss and filter-cake properties; a sand test kit was designed for measurement of the amount of abrasive material; filtration analysis and alkalinity measurements are used for proper diagnosis and maintenance work.

Conclusion

Mud test information from collected data at the well, including pilot testing, augmented with past experience, enables the chemical and petroleum engineer to design and control a drilling mud system for maximum operating efficiency. Collectively, the chemical and drilling engineer has contributed the greatest effort toward the development of present-day drilling fluids, and are looked to for continued improvement towards the reduction of drilling hazards and costs.

(Presented at Eleventh Regional Meeting, Tulsa, Okla.)

MANAGING TECHNICAL OPERATIONS

FRANK K. SCHOENFELD

Vice-President, B. F. Goodrich Chemical Co., Cleveland, Ohio

IN ANY company where technical activities are a major consideration it is essential that the administrative officers properly define the scope of technical interests, determine the technical budget, decide what expansion capital can be made available, and define the procedure for integrating technical effort with the production and sales activities. Management is concerned with the execution of this company policy plus the planning that gives administration the facts necessary for corporate policy decisions.

The first problem is to build technical organizations that fit the environment in which they are to operate. For most technical people this means competitive industry. In the past, technical organizations have been partially shielded from intense competition but all signs point to a drastic change in this situation. If this change were merely an increase in the intensity of technical effort devoted towards upgrading the quality of your corporation's existing products, it could not be termed drastic. Such effort has been on a rising tempo for some years; in many cases to the point of diminishing returns. Nor, could one claim that the increasing technical service that companies are giving their customers is unexpected. Such technical effort is properly a selling expense, easily controlled and evaluated for its effectiveness. The drastic change on the horizon is the intensity of competition that is developing between the technical organizations of industrial concerns.

More than ever before, technical effort on new products and processes must be guided in the light of potential similar efforts by others. The rewards still exist but failures are increasingly costly.

Organization. The first job of management is to organize a research laboratory, a manufacturing development group, a production control group, and a customer service unit so that they fit the environment that exists in a company. Within that environment there is the choice of operating functionally or as a military or line organization. A functional organization makes the best use of technical experts but has the great disadvantage that responsibility is too diluted. Even with careful coordination the individual expertly done portions of the problem often fail to mesh into a final complete whole.

On the other hand the line organization establishes responsibility so clearly that a maximum of operating efficiency in solving a problem is obtained. However, the best use is seldom made of specially gifted experts in this type of organization.

There is nothing sacred about organization forms. For the purpose of maximum efficiency most technical organizations are a mixture approaching a line-and-staff organization. Technical supervisors can have both operating and advisory responsibilities. Certain technical experts can provide specialized services to several groups, and some experienced men may prove most valuable in a strictly planning and consultive capacity. This mixed organizational form works exceedingly well as long as the top technical executive defines precisely the dividing line between advice and authority.

F. K. SCHOENFELD

What Is An Organization?

An organization is generally conceived to be a group of people with defined functions. Because of the importance of human relations in any activity the emphasis is generally placed upon the individual. One can also look upon an organization as a coordinated group of activities. At first thought this may seem to be a mere quibbling with words. However, there are important differences between the two viewpoints. When the emphasis is placed on activities a given individual becomes a part of several organizations. Many individuals in the sale and production department spend a portion of their time on development activities. The reverse is also true in that members of the technical groups often handle production and sales functions. Moreover, the activities of customers and suppliers are often an important part of our organizational functions even though the relationship of these individuals to our organization is indirect.

In managing technical organizations it is practical to emphasize human relationships and consider the overlapping functions of other divisions as part of the environment within which successful operation must be achieved. Solving the many problems involved in the overlapping and integration of divisional activities is an administrative function. A common source of difficulty between functional divisions of a company is the characteristic of some managers to build little empires rather than play on the team. Such behavior, a deplorable example of business immaturity, occurs frequently in technical organizations. The isolation from production and sales problems, the desirability for secrecy, and the specialized language of science tends to encourage this action. *Industrial science can not flourish in glorious isolation.* One can't get away from his environment by ignoring it. Technical organizations are of greatest service when they cooperate within the administratively defined scope of their activities, with other divisions of the company, to the fullest possible extent.

An important technique in the management of large technical organizations is the training, the conditioning, and the selection of personnel so that the group will join automatically in this team effort with other parts of the organization. When this blending of divisional activities is achieved, when rigid departmental walls do not exist, then organization in its most productive form exists.

Individual vs. Team

Human Relations. In the management of technical operations human relations are more than a problem in psychology. While most technical men have normal social instincts and work best in a team effort, it must be recognized by group leaders and their superiors that there must be a judgment on individual effort. Man's innate dignity, his pride in an accomplishment, and his desire for esteem must be recognized. Team work is not herd action; rather it is a tool that enables the technical supervisor to upgrade technical effort in a synergistic manner. A favorite athletic team is cheered as a team, but the individual prowess of each team member is also applauded. Work is so important a part of every technical man's life that frustration through the failure of his superiors to recognize his social and ethical needs leads to an unhappiness that precludes welding that man into an harmonious and efficient team. This recognition must be more than a competitively good salary. The laissez-faire doctrine of Adam Smith is entirely insufficient to handle the aspirations of technical personnel.

The foregoing leads to the importance of selecting able group leaders. These are never in long supply. Young men with technical competence and even brilliance are not too difficult to find. But to develop such men into technical supervisors with an understanding that an executive position is essentially one of trusteeship, is a difficult

assignment. Whenever possible technical supervisors should be chosen from the organization.

After selecting a man who displays initiative, the capacity to accept responsibility, and enthusiasm for his work, it is necessary to teach him what a position of trusteeship involves.

In developing technical supervisors who think broadly from an over-all company viewpoint, rather than from a strictly technical viewpoint, it is valuable to define their responsibilities in terms of corporate policy. This is valuable since it builds a reserve of understanding personnel in back of key positions in other parts of the company.

Corporate Responsibility

Corporate responsibility affects the operations of technical management. How?

First, the stockholders expect not only financial integrity in its broadest sense but also profitable operations.

That general statement is as good a basic definition for describing the technical responsibilities of the group leader in industrial research and development as it is for the officers of a company. Technical men in industry are not engaged in searching for new theoretical knowledge as an end in itself; the prime objective cannot be the enhancement of scientific prestige by publishing papers. The job that industry hires technical men for is to provide the technical know-how needed by the company to operate safely and efficiently, and to develop products that insure its growth and prosperity.

The effective expenditure of research and development funds require a careful consideration by the technical supervisor. He is not discharging his responsibility to the stockholders if he recommends the purchase of every new scientific instrument that comes on the market whether he needs it or not. It is axiomatic that no company should have a technical organization if it is not willing to supply it with all the tools that are needed. On the other hand, one of the most insidious wastes in technical organization is this fetish for scientific equipment. The cost of the tool is generally of small concern. The waste is the thousand of man-hours spent in accumulating data and routine testing without any significant contribution to the development, improvement, or quality control of the product.

Another subtle waste the group leader must train himself to guard against is the pursuit of knowledge down paths that are interesting but unproductive. The problems of perfecting a new product or process are unending. A realization of the point of diminishing returns in technical investigation is instinctive with some group leaders. Unfortunately, poor direction of technical effort is often only apparent in its accumulated effects.

As one of the trustees of company's money the technical supervisor must be taught to combine economic sense with his imagination and technical ability.

Second, employees deserve a management with a social conscience and a willingness to discuss, explain, and act on mutual problems.

At the technical group leader's level in management this employee relationship is a direct personal affair. It starts with introducing a young technical employee into a group where he can start his social contacts. It involves explaining the nature of the company's business, its policies regarding salary, pensions, and vacations. Personnel departments set these policies but they can not replace a man's direct supervisor in providing the necessary personal touch.

The technical supervisor must instill in the young technical employee that the fundamental concept of a technical organization is that the world, in a broad sense is materials and space in which one builds what one wishes.

In all these human relationships an important characteristic in the group leader is that of enthusiasm. A technical group almost invariably has the character of its leader. If he displays enthusiasm for the work, he creates enthusiasm in his associates. Enthusiasm in all activities raises output but in technical effort it is essential if the many disappointments inherent in experimental work are to be surmounted.

Third, the public, whether they be customers, competitors, suppliers, or associates, expect fair, equitable treatment and ethical promotion of the company's products.

For technical men this management responsibility is fundamental to the practice of their profession. Scientific integrity covers this responsibility only in part. Since integrity is so fundamental to technical work and so well understood and practiced, this discussion can be limited to the one point that technical personnel often fail to appreciate. This is, that promoting the ideas of the personnel is part of the job.

Some engineers and many scientists seem to feel that selling themselves and their ideas is unnecessary and beneath their dignity. This not only shows a grave lack of understanding in human relations but deprives them of much personal satisfaction. The pleasure of creating something new and useful reaches its ultimate fulfillment only when shared with others. Selling is a need, that cannot be avoided; it requires skillfully presented creative thinking. Even if one feels that he is in a position to achieve his ends by dictatorial methods, selling the idea preserves the self-respect and generates the enthusiasm in the team that must do the job.

Another aspect of this problem is one's own personal advancement. Some engineering graduates practice their trade, some engage in the profession of engineering. The former are the inarticulate, the latter are those capable of selling their engineering knowledge.

To sell is to convey something to others for a consideration. The prime medium for conveying engineering knowledge is, of course, language. The value of engineering knowledge to others and in turn the extent of the consideration to oneself are greatly dependent upon one's conveying ability.

Superiors and associates deserve the consideration of a well-presented and ethically promoted technical work as well as simple technical skill.

Planning

Procedure. Every individual technical man plans and then organizes his work. Yet the number of technical organizations that merely operate on the basis of ideas, without analysis of these ideas in light of present economics in competitive situations, is large. This is especially true of research organizations. It occurs because everyone recognizes that too rigorous planning of research objectives is liable to stultify and even kill new ideas. However, there is a happy mean that can be achieved between definitely planned research objectives and freedom-of-action research. Even in this freedom-of-action field an economic analysis of the idea is called for at a rather early stage. As a matter of fact most research laboratories find that they gain most of their new ideas not from the undirected exploratory research but rather from by-products of their directed research activities.

Planning consists in determining what, how, and why something should be done. Sales goals in excess of the normal growth trend in the industry can be obtained only when management knows about where it wants to go and why; and when key employees can be inspired with the excitement of the chase. Planning naturally divides itself into two phases. First, to determine the program that will insure progress for one's company. This program defines the goals and details the plan of execution. Second, to coordinate the execution of this program into the whole corporate structure. Planning could be described as organized forethought and corrective hindsight in view of the facts at one's disposal. The major problem in planning operations is to obtain correct facts. In approaching over-all planning problems the technical man who has spent his life in science or engineering must first adjust himself to the idea that while the scientist depends upon provable physical facts, the business man acts on intuition for the most part. Of course it is the paucity of facts in the social and economic fields that forces the executive to resort to intuition and practical psychology. Therefore, it is important to guard against being victimized by enthusiasms and prejudices which will tend to cause a disregard of the facts that could be made available in favor of tips and herd actions.

In this regard it should be recognized that technical organizations tend to grow in a set pattern. Young men, fresh from school, are trained into this pattern. Progress often requires a new perspective and an entirely fresh viewpoint. This can be accomplished by hiring a man who gained his experience in a different environment or by hiring a consultant. Good consultants can bring to a technical organization a broad extensive view of many problems.

(Continued on page 33)

Frank K. Schoenfeld has been associated with the Goodrich organization since 1927. His early research work in vinyl resins led, in 1939, to his appointment as group leader of the research team that subsequently developed the manufacturing process of producing vinyl chloride by the reaction of acetylene and hydrogen chloride and its subsequent emulsion polymerization to electrical grades and general purpose grades of polyvinyl chloride. Since that time the development of the many variations of vinyl resins has been under his direct supervision. Prior to his appointment in 1946 as vice-president-technical he was technical director for the company responsible for all technical operations and development, including the three Government synthetic rubber plants operated by the company. He is the author of numerous papers on and the holder of several patents in surface chemistry of piements, adhesives, synthetic rubber, etc.

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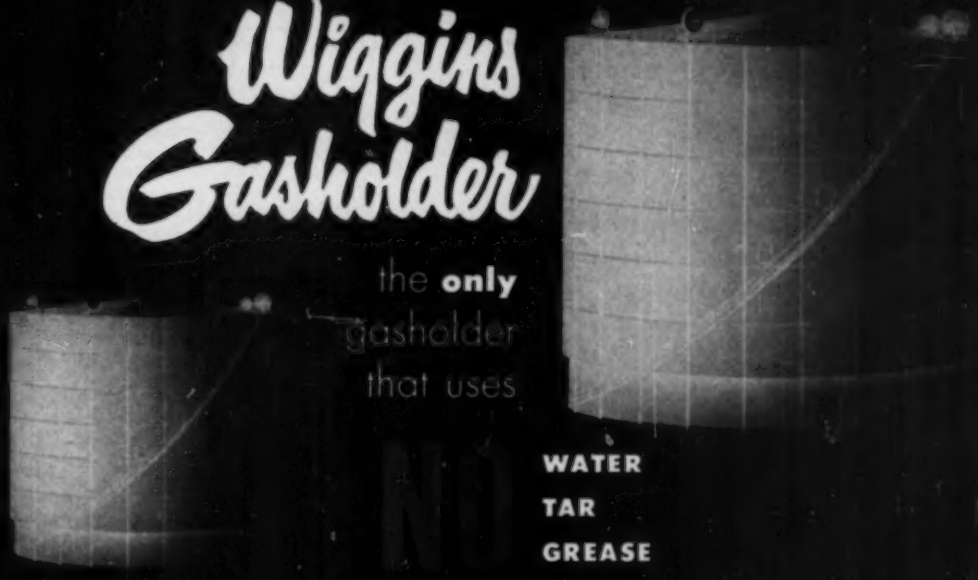

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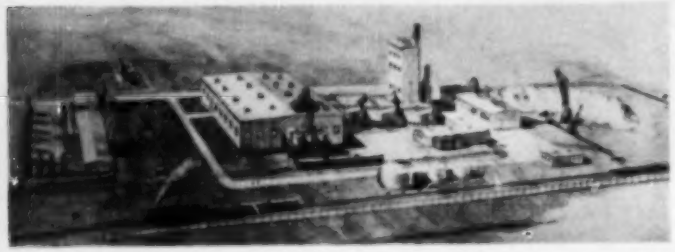

This new $3,000,000 Filtrol Salt Lake City plant is scheduled for operation in January, 1951. Capable of making a full line of Filtrol products it is especially designed for the manufacture of an improved new catalyst for petroleum cracking. This catalyst is particularly suitable for the manufacture of high octane gasoline and will promote major economies in those refineries which generally require a catalyst of the synthetic type.

The manager of the Salt Lake City plant will be A. D. Yates, who previously was superintendent of the Filtrol California plants. The initial quota of personnel for the operation of the new plant is estimated at approximately 150 in direct plant operations.

BROOKHAVEN PILE BEGINS OPERATING

The nation's largest and most powerful atomic research reactor began operating Aug. 22, according to Dr. Leland J. Haworth, director of Brookhaven National Laboratory, nuclear research center supported by the Atomic Energy Commission.

At 2:30 A.M. Dr. Lyle B. Borst, in charge of the pile, signalled for removal of control rods, thereby starting the initial chain reaction. Loading of uranium to bring the reactor to its full-designed power will continue for several months. Meanwhile, experiments will begin, with the reactor operating 24 hours a day.

The new installation is an air-cooled, graphite-uranium pile which, at its designed power level, will develop heat at a rate of 30,000 kw., several times that of the A.E.C. reactor at Oak Ridge National Laboratory. Engineering design and construction were carried out by The H. K. Ferguson Co.

The Babcock and Wilcox Company of Barberton, Ohio, served as engineering consultant in the final stage of construction, and the Servo-Mechanism Laboratory of the Massachusetts Institute of Technology, Cambridge, Mass., designed and engineered the reactor control system.

The project consists of five major structures, largest of which is the reactor building proper. Two laboratory wings, with a total of 30,000 sq.ft. of floor space, are located on either side of the reactor building, and a "hot" laboratory nearby provides 33,000 sq.ft. of floor space for research with radioactive materials of high intensity. The air which cools the reactor is moved by large fans which are driven by 1500-hp. motors, through ducts large enough to accommodate a New York subway train. They are located in a "fan house" on the hill near the reactor and finally drive the air up a 320-ft. stack made of reinforced concrete, 32 ft. in diameter at the bottom and 19 ft. at the top.

Passageways in the graphite cube of the reactor permit circulation of cooling air to carry away the heat generated by fission. Under and around the reactor are labyrinthine passages, or ducts, through which cooling air enters and leaves. Air speed varies from some hundreds of miles per hour in the narrow graphite passageways to 40 miles per hour in the ducts.

In the fan house, specially designed 12-ft. centrifugal compressors rotate at 3600 rev./min. to draw 300,000 cu.ft. of air every minute through the pile cooling system.

Argon, which comprises about one per cent of the earth's normal atmosphere, becomes radioactive in passing through the reactor. However, this radioactivity immediately begins decaying. In addition, it is diluted many thousands of times after it leaves the stack, by a process of mixing with the natural atmosphere. Decay and dilution together render the radioactivity harmless.

If the cooling air carried particles or dust, some of this material, too, might become radioactive. To avoid this, the air is filtered both before and after it passes through the reactor.

If weather conditions threaten to cause a poorly diluted flow of reactor gases over one spot long enough to raise the radiation exposure above the permissible weekly limit at ground level, the reactor will be shut down. To provide detailed technical information, the Meteorology Group attached to the reactor operates a weather station and two towers, 420 and 160 ft. high. Meteorologists measure temperature and wind differences between ground and the tops of the towers. Thus they can determine how conditions affecting rates of dilution of the cooling air from the reactor vary between positions only a few hundred feet apart.

The laboratory's health physics and instrumentation department maintains a branch at the reactor to assure that no one is working under dangerous conditions or can be unduly exposed to radiation. This program is divided into personnel monitoring and building survey.

Personnel monitoring begins at the entrance, where each employee receives a film badge which is tested weekly and a pocket meter tested daily, for signs of overexposure. All employees whose work might result in contamination go to special locker rooms to change to protective clothing. After work they are monitored for contamination, and scrub themselves with soap and water, if necessary. Their discarded protective clothing is treated in a special decontamination laundry.

At Hanford and Oak Ridge, the average radiation received by all workers is less than half the amount that residents of Rocky Mountain cities receive from cosmic rays. The average for A.E.C. workers in an entire year is considerably less than that received by many people from natural sources, radon gas, radioactive mineral waters, etc.

The A.E.C. rule is that no worker shall receive more than 0.3 roentgen a week, a rate of exposure which experts believe would do no damage even if continued a lifetime.

The building survey includes setting up extra lead shielding, testing floors, tables, equipment and air for contamination, and other precautionary measures. This is standard procedure every time a "hot" or radioactive experiment is conducted at the reactor itself or in one of the laboratories. As a planning guide to health physicists, radioactive sources used in experiments in various parts of the area are spotted on a large map, much as a city's fire hazards may be plotted for the guidance of the firemen.

Research workers set aside "hot" wastes in labeled bottles and carefully limit the amount of radioactive material they pour down the drains of a special system. Water from the sinks passes first into hold-up tanks, where automatic equipment collects a continuous sample. If tests show long-lived radioactivity above a prescribed limit, the contents of the hold-up tank are pumped into steel tanks for permanent storage. When the

(*Continued on page* 16)

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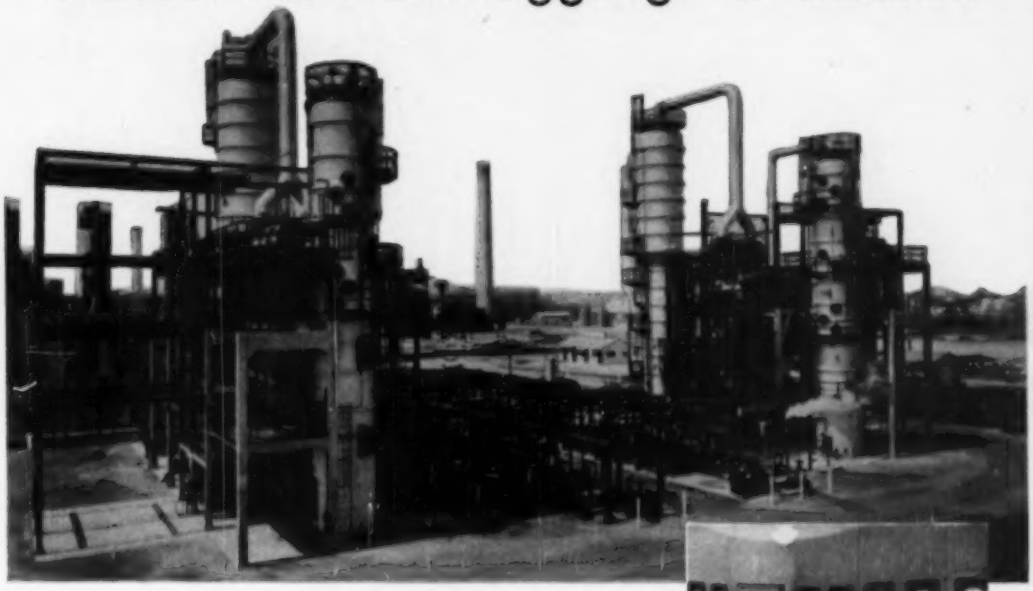

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BROOKHAVEN PILE

(*Continued from page* 14)

samples decay to safe limits, the water is released from the basin into the sewer system.

Brookhaven waste water is tested twice more before it flows into uncontrolled drainage: at a pool where sewage is subjected to a standard bacterial treatment which precipitates out residual radioactive contamination, and at sand filter beds which capture more of what is left.

CH.E. PROFESSORS FOR FULBRIGHT PROGRAM

This year, approximately 300 awards for United States citizens to serve as visiting lecturers or to undertake research abroad during the academic year 1951-52 have been announced by the Department of State under the provisions of the Fulbright Act. Many of the awards are open to college professors, research scholars and specialists in engineering and related fields.

In chemical engineering the Conference Board of the Associated Research Councils, 2101 Constitution Ave., Washington 25, D. C., indicates two opportunities. One is in the Netherlands at Delft Technical Institute in chemical technology. The research would be in chemical technology under Professor Waterman.

In the United Kingdom, Kings College, Newcastle, a constituent college of the University of Durham, needs a visiting lecturer in chemical engineering. The lecturer would be asked to take over instruction in chemical plant design and if possible to give courses on the transport and storage of materials, principles of automatic control.

Closing date for filing applications is Oct. 15, 1950. Other openings in chemistry and related fields are known to the conference board and further information may be obtained from it.

SNELL TO BUILD LABS.

Foster Dee Snell, president of the research and engineering firm of Foster D. Snell, Inc., New York, announced last month that contracts for the first unit of new laboratories in Bainbridge, N. Y., had been granted. Plans call for the erection of a single wing of a structure which later will provide for four wings with extensions. This first unit will be occupied by its Supplee division conducting vitamin work and supplying animals to other laboratories.

The project does not envisage any change at present in the activities in New York. It does provide for future

(*Continued on page* 20)

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Valve Inch Size	Opening Pressure Ounces		Vacuum Opening Ounces
	Minimum	Maximum	
2	3.2	16	0.5
3	3.3	16	0.5
4	2.5	16	0.5
6	2.5	16	0.5
8	2.0	16	0.5
10	2.0	16	0.5
12	2.0	10	0.5
16	2.0	8	0.5
20	2.0	6	0.5
24	1.5	4	0.5

NOTE: Pressures in this table are for cast aluminum cover, and they will differ from other metals. Pressure ratings require a manufacturing tolerance of plus or minus 5 per cent. Vacuum opening can be increased.

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F. J. CURTIS, P. R. TARR DIRECT MONSANTO PREPAREDNESS PROGRAM

F. J. CURTIS

P. R. TARR

Francis J. Curtis, vice-president and director of Monsanto Chemical Co., and President of A.I.Ch.E. in 1949 has been appointed director of industrial preparedness for the company with headquarters in Washington, D. C. At the same time Philip R. Tarr, European technical representative has been appointed assistant director. Monsanto's Washington office, under the direction of H. W. Yeagley, will continue its operations as formerly.

Mr. Curtis, a graduate of Harvard University, has been with Monsanto since 1915. As a vice-president and director of the company, Mr. Curtis has been in charge of sales coordination since 1948, and is secretary of the executive committee. In 1945 he served as technical consultant to the Chemical Corps investigating Germany's chemical industry.

Mr. Curtis, who was vice-president of the A.I.Ch.E. in 1948 and director 1945-47, is past chairman of the American Section of the Society of Chemical Industry.

Mr. Tarr received his B.S. and M.S. degrees from Pennsylvania State College. During World War II, he served as a colonel in the Chemical Corps in charge of chemical intelligence activities. Mr. Tarr, who served four years as assistant to the executive vice-president was recently appointed Monsanto's European technical representative with headquarters in Paris. This assignment has been postponed.

ALCOHOL PLANT IN TRUJILLO COMPLETED

A plant to make absolute alcohol from molasses in Ciudad Trujillo, Dominican Republic was recently completed according to R. S. Aries & Associates, consulting engineering firm of New York.

The new plant, the Destileria Universal, has a rated production of 7200 gals. a day, or about 2.5 million gallons a year, of absolute (100%) ethyl alcohol. It will use about 6.5 million gallons of local blackstrap molasses, thus easing the disposal problems of this sugar by-product of the island. The plant is also equipped to produce rum over and above the absolute alcohol capacity. In view of local conditions, it has been designed to withstand earthquakes and winds with a velocity of 180 miles an hr. One of the features is the generation of electricity from high pressure steam; the resulting low pressure steam is used in the process. The plant is completely instrumented for automatic operation and uses benzene for the dehydration of the alcohol.

The cost of the alcohol plant was more than $600,000, and it required one year to complete from breaking ground to initial operation. The output of the plant will be used for blending with gasoline, of which about 15 million gallons are consumed annually in the Republic.

N.S.P.E.'S STATEMENT ON COLLECTIVE BARGAINING

The Board of Directors of the National Society of Professional Engineers, 1121 Fifteenth St., N. W., Washington 5, D. C., recently adopted a statement of principles regarding collective bargaining by professional employees.

The NSPE has taken a stand against collective bargaining for professional employees for a number of years and in the new statement of principles, which may be obtained from the group in Washington, the stand is made more positive. It maintains that it is definitely unprofessional for an engineer to join a heterogeneous labor union. Some exceptions are made, notably for those who do not join voluntarily, and for the engineers-in-training who join the labor union as a step toward obtaining practical engineering training.

The group bases its objection on the fact that engineers, because they have individual capacities and talents, cannot be considered on a collective basis but must be dealt with individually.

PANJAB UNIVERSITY NEEDS SCIENTIFIC BOOKS

The latest books on physics, chemistry, chemical engineering and metallurgy are greatly needed at the University of Panjab, in Lahore, Pakistan, according to information received at CARE headquarters, 20 Broad St., New York 5, N. Y. Those needs were listed by Mohammad Afzal, deputy registrar, to a CARE representative who visited the university to discuss the way in which it might best be helped through the CARE Book Fund.

"Our immediate needs now," Mr. Afzal told CARE'S representative, "lie in the technical fields. It is very difficult to obtain such books in Pakistan—especially the latest scientific information. We are reorganizing our physics department, and we also have a great need for more books on chemical engineering, chemistry and metallurgy. . . ."

Pakistan is one of 20 countries now reached by the book plan which CARE added to its food and textile package service last year. Americans who wish to help provide the books needed by the University of Panjab can send their contribution to the CARE Book Fund at the agency's New York address or any local CARE office.

DEL JACK CO. FORMED IN LOS ANGELES

The Del Jack Co., Beverly Hills, Calif. was recently organized to handle the equipment for the Hills-McCanna Co., New York, Power Products Co., New York, Packing Engineering Co., Cranford, N. J. and the Pennsylvania Salt Manufacturing Co., Philadelphia, Pa., for the latter's corrosion resistant cements and paints.

Delbert E. Jack's recent return to California in order to establish his own company as manufacturers' agent was referred to in the March issue of C.E.P. He was formerly vice-president in charge of engineering and sales for The Duriron Co., Inc. He retains his position as West Coast technical adviser for that company.

CHEM. SPECTROSCOPY MEETING, FEB. 28-MAR. 2

The 1951 Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy will be held at the William Penn Hotel, Pittsburgh, Pa. Feb. 28-March 2. The Conference is jointly sponsored by the Analytical Chemistry Group of the Pittsburgh Section of the American Chemical Society and the Spectroscopy Society of Pittsburgh.

An exposition of modern laboratory equipment will be a feature of the conference.

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Send for a copy of Bulletin 816, which describes these pumps in detail. No cost, no obligation.

This drawing shows how the Series R DURCOPUMP operates in priming. When the pump is started, the water is thrown upward into the air separator through port A, while air is drawn in from the suction line at the eye of the impeller. Water and air pass into the air separator. The water, baffled by plate B, returns through port C. The air passes into the discharge line. When the air in the suction line is evacuated, the impeller discharges liquor through both ports A and C.

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NEW ETHYLENE OXIDE UNIT FOR CARBIDE

Above are some of the new facilities for producing ethylene oxide at the Whiting (Ind.) plant of Carbide and Carbon chemical division of Union Carbide and Carbon Corp. This is part of the corporation's program to increase ethylene glycol output.

Additional facilities at Whiting now under construction are expected to be placed in operation late in the year.

At Institute, W. Va., Carbide is already producing ethylene glycol from new units which went into operation earlier this year. Further expansion of the production capacity at this plant is also under construction which will be completed and placed in operation during the last quarter of 1950. Present annual rate of production for ethylene glycol in the U. S. is 210,000 tons. New facilities of all producers may push this figure to exceed 320,000 tons by early 1951.

SNELL LABS.

(*Continued from page 16*)

expansion, and for long-term projects in a rural area where living costs for personnel are substantially lower. When conditions require more space, separate departments can be transferred from New York to the new location to relieve congestion in its present building at 29 W. 15th St., in New York. The next unit to be constructed will be either a drafting room for its engineering department, or a pilot plant to release the area used in New York at present for that purpose.

MILITARY SERVICE PLAN FOR S. O. N. J.

Families of employees of Standard Oil Company (New Jersey) called into the armed forces will be protected against financial hardship by a company military service plan. In addition to provisions for dependents, the plan also includes a number of benefits for employees without dependents. Among other provisions it guarantees an employee his old job, if available, or as nearly an equivalent position as possible when he returns from military service.

The company first established a program to alleviate financial hardship to families of employees called to service soon after Pearl Harbor, and another program was kept in effect after the end of World War II to permit employees who were members of reserve forces to attend training encampments or cruises without financial loss to themselves.

The present program, effective Aug. 1, was decided upon when a number of employees who are in the reserves were alerted for active service and others became subject to draft calls.

Under the program, an employee entering the Armed Services, whether by voluntary enlistment, draft, or as member of a reserve force called to active duty, is granted a military leave of absence from the company. This means that his employment is protected and that his service credits for employee benefit programs involving length of service are not interrupted.

Dependents of such an employee will receive monthly payments from the company during the breadwinner's period of active military service. These payments will be equal to the difference between the employee's regular company pay and what he is paid in the service, with a maximum fixed at one half the employee's regular company pay.

The plan emphasizes help to the wives and children of employees who receive minimum military pay. For example, in the case of an employee receiving a salary of $300 a month when he enters the Armed Services at $75 a month, the company would pay his dependents $150 a month, or half of his civilian salary. If the same employee received $200 a month military pay, the company would pay his family $100 a month.

An employee with more than one year's service with the company, whether he has dependents or not, receives a lump sum payment equal to two months' salary when he enters military service. When vacations cannot be taken prior to entry into military service, the employee also will receive his vacation pay.

Group insurance may be continued for the first 90 days of military service. If the employee dies while in military service, his dependents will receive survivor benefits from the company based not only on company service but on time spent in the armed forces.

FLUID CRACKING UNIT FOR GULF

Contract for the construction of a 60,000 bbl./day fluid catalytic cracking unit was awarded early in August by the Gulf Oil Corp. to The M. W. Kellogg Co. of New York. The plant will be erected at the company's refinery at Port Arthur, Tex., and the anticipated output will be approximately 20% greater than that of any similar installation.

The new fluid unit is scheduled for completion during the late summer of 1951. Cost of the addition, with auxiliary equipment necessary for its operation, will be approximately $8,000,000.

CONFERENCE ON INDUSTRIAL RES. AND DEV.

The second annual South Dakota Conference on Industrial Research and Development will be held Oct. 13 and 14 at the Alex Johnson Hotel, Rapid City, So. Dak.

Sponsored jointly by the South Dakota School of Mines and Technology, the Black Hills Research Institute and the Research and Development Association South Dakota School of Mines and Technology, the conference, with an educational and informative objective, seeks to promote interest and knowledge in the need, aims and advantages of industrial research in developing the natural resources of the region and in furthering the development of regional and local industry.

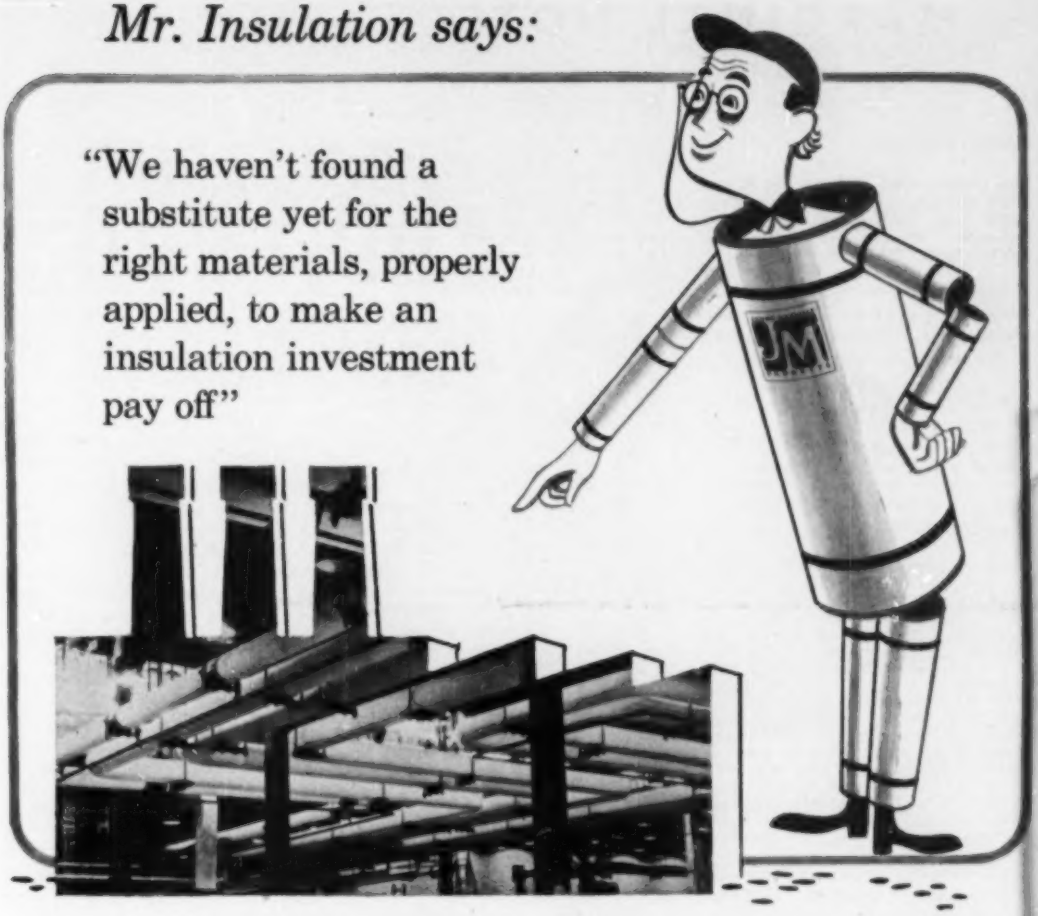
This year the conference will stress the aspects of industrial research applied specifically to regional and local interests in industry and resources.

For further information and registration write: Chairman, South Dakota Conference on Industrial Research and Development, South Dakota School of Mines and Technology, Rapid City, S. Dak.

(*News continued on page 32*)

Mr. Insulation says:

"We haven't found a substitute yet for the right materials, properly applied, to make an insulation investment pay off"



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2... THE RIGHT APPLICATION: Here again Johns-Manville's long experience in the field of insulation can be of value to you. Insulation engineering advice plus the services of insulation contractors trained in Johns-Manville methods of correct application are at your call.

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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

Control Essential to Planning

The Organization of Industrial Scientific Research. C. E. Kenneth Mees and John A. Leermakers. Second Edition. McGraw-Hill Book Co., Inc. (1950) 333 pp. + viii. $5.00.

Reviewed by George Granger Brown, Chairman, Department Chemical and Metallurgical Engineering, University of Michigan, Ann Arbor, Michigan.

THIS is a complete revision of an earlier book of the same title published 30 years ago. All aspects of industrial and scientific research administration are covered from the general principles to the details of the design of physical facilities.

Only those things can be planned which can be controlled, and plans are carried out only as long as control is effective. . . . The two requisites for planning are knowledge of the processes to be controlled and physical power to control them. When planning is extended to fields of which little knowledge is available and from things which can be controlled to those which in their nature are uncontrollable, planning fails. . . . When these principles are applied to the planning of scientific research, the kinds of research which can be planned best are bound to be those which are least fundamental. . . . The last stages of development can be planned with considerable certainty.

The authors have naturally drawn upon their own extensive experience with the Eastman Kodak Co.; but the inclusion of statements made in response to many questions asked of manufacturing and research divisions of other companies makes the volume a concise but complete treatment of scientific research as it is organized and administered in American industry.

It seems to be generally agreed that the most successful laboratories are those in which the director has assumed and exercised almost complete control of the selection of work. . . . It has been the experience of a surprisingly large percentage of research directors that they have had to assume the responsibility for certain investigations without the approval of—or, indeed, with the expressed disapproval of—some of the other company executives. . . . New products are not found by attention to them on the part of the management of the laboratory. They arrive spontaneously from the mass of ideas and suggestions coming from the research workers themselves, and the laboratory direction must encourage initial work on these ideas and then select from them those which are worth larger scale development. If there is a lack of ideas in a laboratory, it is generally to be traced to a lack of encouragement of this development of ideas by the scientific workers themselves. This condition may occur in departments run by a dominating personality who discourages the ideas of others even though he may do so unconsciously. Healthy laboratories have more ideas than the company can possibly develop. The problem is one of selection and not of origination.

The various successful plans of organization and administration are presented with an open mind.

On another aspect the authors state that "experienced research directors have pointed out repeatedly that every effort should be made to reduce formalization in a laboratory to the minimum consistent with satisfactory operation. . . . There is a danger in an organization chart—danger that it be mistaken for an organization. Advantages of functional organization are that it encourages scholarship and the development of experts; it has stability and security for the man who wants to be a specialist; it encourages more lasting areas of common interest with scientists in other institutions. On the other hand functional departments sometimes develop vested interests in space and facilities that are disadvantageous and difficult to deal with. Project organization promotes flexibility in the use of men, space and facilities. It broadens the experience of the technical staff. It tries out and develops leaders at the working level. It gets things done. In practice large laboratories incorporate elements of both functional and project organization. A large measure of project organization is favored for work that has concrete and practical objectives. . . ."

The volume is highly recommended to everyone who has anything to do with the administration of scientific research whether it be in industry, government, or elsewhere. It is stimulating and interesting, and should be read by all those research workers who wish to understand the administrative problems connected with their activities.

Analyzing Fumes, Dusts and Chemicals

The Chemistry of Industrial Toxicology. Hervey B. Elkins. John Wiley & Sons, Inc., New York. (1950) 406 pp. $5.50.

Reviewed by Volney R. Croswell, Manager of Safety, Naval Stores Department, Hercules Powder Co., Wilmington, Del.

PROTECTION of workers from industrial poisons is primarily the responsibility of industry. Dr. Elkins has written a book that will appeal especially to those in industry who can recognize this responsibility and who are in a position to do something about it—chemists and engineers. There are many fine books and papers dealing with industrial toxicology "written primarily from the medical point of view" but the men closest to actual working conditions have long needed a book like this to give them a better understanding of the problems of the industrial physician. Symptomology, pathology and treatment purposely are omitted. Emphasis is on the substances themselves, and the nature of their more harmful effects. This book is readable, the style is simple, the arrangement of material logical to one trained in chemistry. The book contains a minimum of medical terms. References to the bibliography in the back of the book are made by the use of unobtrusive numbers running consecutively through the entire book.

After a chapter on definitions, Dr. Elkins discusses evaluation of hazards.

Chapters III-X classify and discuss actual and potential industrial poisons. Each substance is given a subheading in bold-faced type and under this are the facts of most interest concerning it. There, available at a glance, is the essential information on the toxicity of the material.

On page 102 Dr. Elkins states that the narcotic action of benzene is of minor importance compared to its chronic effects. "A single severe exposure to benzene is apparently no more serious than a similar exposure to many other solvents." Our own experience is quite different. In two large plants using benzene for extraction over periods of eighteen and sixteen years respectively, no cases of chronic benzene poisoning have been encountered. During this time six men were overcome by benzene vapors, three of whom died and three recovered completely.

The author of any technical book faces the hazard of making statements which are correct at the time they are written but which are incorrect by the time the book gets off the press. In relation to ethylene oxide there appears the statement on page 121. "No data are

(*Continued on page 24*)

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PULSAFEEDER CHEMICAL PROPORTIONING PUMPS

MARGINAL NOTES

(*Continued from page 22*)

available on industrial poisonings." Several cases of injury to the skin by ethylene oxide were reported last fall (Richard J. Sexton and Edward V. Henson, "Dermatological Injuries by Ethylene Oxide," *Journal of Industrial Hygiene and Toxicology*, 31:297-300, September, 1949).

There is particular value in the material gleaned by Dr. Elkins from his experience in industrial hygiene in the Commonwealth of Massachusetts.

The chapter on maximum allowable concentrations is the best covering of this subject this reviewer has seen.

The author mentions 80 chemicals, fumes or dusts which are commonly encountered in air and gives the status of methods of analysis for each. Most of these are modifications of published procedures which have been used by the Massachusetts Division of Occupational Hygiene and, therefore, have the advantage of being tested methods.

Laboratory Fractionation

Laboratory Fractional Distillation. Thomas P. Carney. MacMillan Co., New York. (1949) 260 pp. $5.75.

Reviewed by H. H. Reamer, California Institute of Technology, Pasadena, Calif.

THE author has presented in a concise, systematic manner the rapidly growing background of experimental procedures, ingenious apparatus, and methods of predicting and evaluating the performance of laboratory fractionating equipment. The theoretical considerations upon which most of the predictions have been based are simply and directly stated and follow conventional methods. Comparisons of predicted and theoretical behavior presented have not been carried as far as one might desire, considering the utility and effectiveness of existing methods of predicting the characteristics of small-scale distillation equipment.

The approach to the selection of the proper column to employ for the accomplishment of a particular objective is specific and useful. Of interest to the student or laboratory worker who is not familiar with this class of apparatus is the description of the several common types of laboratory columns.

Detailed and semiquantitative specific diagrams illustrating the construction of columns for various types of fractionation are worth while and represent an important part of the contribution of this book. The presentation of the means of testing fractionating equipment is particularly useful and includes much that is relatively new. Accessory equipment found useful in connection with the operation of fractionating equipment is discussed. Some additional information concerning high-vacuum techniques may be necessary for the uninitiated laboratory technician to undertake work in this field.

A number of interesting applications of special fractionating columns are presented along with a discussion of vapor-liquid equilibrium apparatus. The author considers azeotropic and extractive distillation from a relatively descriptive standpoint and indicates the practical procedures to employ. Consideration is given to micro and semimicro fractionation and limited mention is made of molecular stills.

A satisfactory bibliography and an extensive index are included. The book is clearly written, specific in detail, and the ć grams are sufficiently complete to permit a glass blower, familiar with laboratory apparatus, to build a large part of the special equipment described. It is believed that this book is primarily of use to the laboratory worker or the more advanced student confronted with fractionation problems.

Bane of Engineer's Life—Writing Reports

Practical Report Writing. Selby S. Santmeyers. International Textbook Co., Scranton, Pa. (1949) 118 pp. $2.75.

Reviewed by R. R. White, Professor of Chemical Engineering, University of Michigan, Ann Arbor, Mich.

THIS book discusses the importance of writing good reports, their preparation, composition and organization. The book considers the general problems of writing all types of reports rather than the writing of technical reports with which engineers are most concerned. A relatively large number of brief examples illustrate the various points which the author wishes to emphasize and exercises are included. The style of the book is clear and concise, and the treatment of the subject is on an elementary level.

While the book is admirably suited to developing the report writing abilities of high school graduates, the elementary level of presentation does not make it suitable for most college graduates and engineers. As usual, the examples are all illustrative of good report writing. From experience, this reviewer feels that examples written poorly, followed by criticism, and the examples written well would be more effective.

The Impress of Authority

Kent's Mechanical Engineers' Handbook. 12th Edition—2 Vols. John Wiley & Sons, Inc., New York. Design and Production, 1611 pp.; Power, 1409 pp. (1950) $8.50 each. Edited by J. K. Salisbury and Colin Carmichael and a Staff of Specialists.

STANDARD in the mechanical engineering field, but perhaps not so well known in the chemical engineering field, is the two-volume (Kent's) Mechanical Engineers' Handbook. This new, 12th edition (the eleventh volume was published 12 years ago) offers the mechanical engineer an enlarged and improved version, and to chemical engineers it brings a ready handbook of information which forms the backbone of mechanical engineering.

A brief word of history is perhaps in order. The book was first published in 1895 by W. Kent, who edited eight editions. Three editions were edited by his son, R. T. Kent, and this last and 12th edition is edited jointly by Colin Carmichael and J. Kenneth Salisbury.

The handbook is divided into two parts, or volumes, as was the case with the eleventh edition, one volume called Power; the other, Design and Production. The Power volume covers the field of heat power engineering and transportation, as well as fluid flow, and both volumes have been organized in sections. Power has been organized into 20 sections: basic ingredients of the power process, air fuel, heat and steam, are covered in the first four; service functions of pumping and piping in sections 5 and 6; power-producing equipment, boilers, etc., in sections 7, 8, 9 and 10; sections 11 and 12 are on refrigeration, heating, ventilating, etc.; transportation is covered in 13, 14 and 15; electric power is in section 16. Atomic energy, instrumentation, codes, etc., make up the last four sections.

In the Design and Production volume which is directed primarily to engineers who design and manufacture machinery, appliances, mechanical equipment, etc., there are 28 sections arranged broadly as to selection of materials, design principles, design and selection of machine components, production processes, production plan equipment and mathematical tables.

There can be no question about the authoritativeness and excellence of this handbook, since the author of each section is well known in his field and has carefully written the chapter components.

Book Received

Metals at High Temperatures. Frances H. Clark. Reinhold Publishing Corp., New York (1950) 372 pp. $7.00.

(*More Marginal Notes on page 30*)

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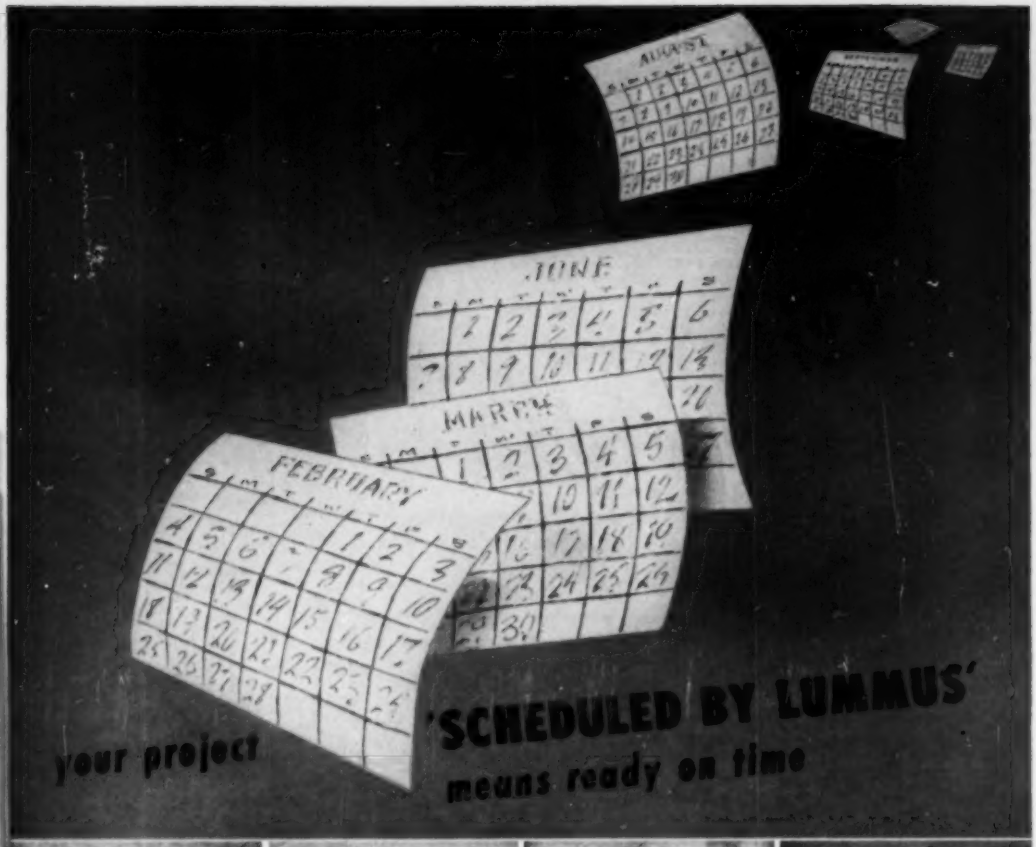

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Chemical Engineering Progress

DATA SERVICE

CHEMICALS

1 • INDUSTRIAL CHEMICALS. An illustrated catalog of the industrial chemicals, their properties, grades, uses, packing, etc., manufactured by the Blockson Chemical Co. It covers industrially important material such as trisodium phosphate, alumina hydrate, sulfuric acid, tetrasodium pyrophosphates, etc. Also has a section of tables of useful information; hardness of water, pH tables, atomic and molecular weights, units of measurement, temperature scales, etc.

2 • DICYCLOPENTENYL ALCOHOL. From Rohm & Haas Co. technical sheets on this new compound which give physical properties, specifications, structure. Section on reactions of the chemical, suggested applications, etc. Makes insoluble coatings when polymerized, plasticizers, surface active agents, etc.

3 • PHARMACEUTICAL CHEMICALS. A handbook of the pharmaceutical chemicals manufactured by Dow Chemical Co. Divided into two parts; pharmaceutical chemicals and pharmaceutical intermediates. These sections covering about 80 different compounds are described in the same pattern—structure or formula, properties, specifications, packing, and uses.

4 • 5 • 6 • ACETATES. Three bulletins of the Niacet chemicals division of Union Carbide and Carbon Corp. cover three different types of acetates, vinyl acetate, a zinc acetate and a sodium diacetate. The bulletin on vinyl acetate (*4*) presents in detail physical and chemical properties, specifications, shipping and handling information. Instructions on unloading tank cars, handling and storage, a test to identify diphenylamine in the vinyl acetate, plus information on uses. (*5*) Follows the same pattern for zinc acetate and (*6*) for sodium diacetate.

7 • SURFACTANTS. Antara Products have coined a word surfactants, meaning surface active agents, and to describe these products have issued an easy-to-read bulletin. Covers the action of surface active agents acting as detergents, disperents, wetting agents, emulsifiers, etc. Final pages are given over to the types of surfactants made by Antara, their type, name and uses.

8 • TUBULES. Liquid chemicals sealed in ampoules called Tubules by the Smith, New York Co., Inc., are listed in a new catalog by the company. The ampoules come in five, ten and twenty-five gram sizes, and are designed for protecting chemicals against change and contamination. The booklet lists 522 compounds the company is making available in tubules. Prices are given per ampoule in lot quantity.

9 • COLMONOY NICROBRAZ. For brazing stainless steel the Wall Colmonoy Corp. has a new heat and corrosion resistant alloy termed nicrobraz. It is a stainless type which can be used to braze 300-400 series stainless steel inconel, monel, etc.

10 • S.P.M. Sodium Parachlorobenzenesulfonate Monohydrate is being offered by the Pennsylvania Salt Manufacturing Co. for evaluation. A bulletin describing in detail the possible applications, physical properties has been prepared. Concentrated solutions of the material increases, water solubility of materials such as aniline, cresol, and benzaldehyde. The sodium salt will act as a catalyst and can be used as a peptizing agent for casein soya products, used in pigment flushing, ore flotation, etc.

11 • FUNGISTAT. The use of paradichlorobenzene as an effective agent for the control of mildew is the subject of a technical bulletin of Monsanto Chemical Co. Gives data on the control of fungi on shoes, canvas, wool and paper book. Various fungi were used, the book gives photographs showing the protection given by paradichlorobenzene. Use, recommendations, limitations, and instructions for handling, as well as a bibliography, are given in the bulletin.

12 • DIALLYL AMINE. In pilot plant production by the Edwal Laboratories, Inc., diallyl amine for use by the pharmaceutical, resin intermediate, and organic industries.

14 • ION EXCHANGE RESIN. A new medium-capacity cation exchange resin, Amberlite IR-105G, by the resinous products division of Rohm & Haas Co. It replaces two others

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in the company line since it combines good hydraulic behavior with high capacity and regeneration efficiency. Phenolic-type resin in granular form. Notes on its behavior and applications are available.

BULLETINS

16 • KINETIC MANOMETER. A new instrument for indicating flow at an orifice through differential pressure is in production by the Fischer & Porter Co. The pressures are transmitted pneumatically or electrically to remotely located recording and controlling instruments. Bulletin available. Instrument is stainless steel. It eliminates seal pots, mercury and other manometer fluids, packing gland, etc.

17 • HAVEG EQUIPMENT. Haveg Corp. manufacturer of corrosion resistant equipment has a completely new bulletin describing all equipmeat. Bulletin gives general information and data on grades of Haveg, physical and chemical properties of the material, and shows some of its machining characteristics. Equipment covered is valves, pumps, pipes, tanks, fume ducts, towers, agitators, etc. Gives tables of chemical resistance of Haveg, standard dimensions and sizes of all equipment, method of installing, threading, etc.

18 • CIRCULAR BIN DISCHARGER. For discharging pulverized granular and soft materials that make puck or arch and refuse to discharge, the Stephens-Adamson Manufacturing Co. has a new circular bin discharger. The units are installed in the bin, consist of a revolving cone with projecting fingers which agitate the material over a large area of bin bottom. The agitated material is swept to a discharge outlet. For materials that arch in the bin over the cone a vane-type arch-breaker can be added to the top of the rotating cone. Three types are available and the model has been used on wood chips, ammonium sulfate, cement, zinc oxide, soda ash, etc.

19 • COOLING TOWER. A loose-leaf insert of J. F. Pritchard & Co. series SRF cooling towers. Redwood construction with a steel pipe distribution system and bronze spray nozzle. Table gives capacity and dimensional data for six different models.

20 • PUMPS. A catalog of industrial pumps by Nagle Pumps. Shows the types of impellers available, gives data on priming, pump installation, materials of construction, tables of discharge, sizes, dimensions, weights of the various kinds of pumps made by the company. Vertical shaft models also. A supplement gives capacity curves and data on a new chemical pump with an open impeller for corrosive applications.

21 • PROCESSING EQUIPMENT. A descriptive bulletin of processing equipment for the chemical industries made by the Read machinery division of The Standard Stoker Co. Equipment described and pictured is elevators, dump bins, sack-cleaners, blenders, sifters, mixers, acetylators, blenders, special machinery, vacuum driers, etc.

22 • FLOCSETTLER. An eight-page technical bulletin describing a flocsettler of the American Well Works for use in waste treatment. Shows a description of the unit plus the action of mixing and blending, flocculating and softening, slurry recirculation, and settling.

23 • WATER TEST. A rapid accurate one-minute test for determining water hardness is described in a new bulletin by Hall Laboratories, Inc. Pictures procedures, reagents, equipment, etc. Based on a color change and accuracy to 1 p.p.m.

24 • AIR-RELIEF TRAPS. For venting air from any liquid under pressures such as gasoline, water, or other solvent, Armstrong Machine Works has a two-page folder describing the types of air-relief traps it makes. Shows correct installation, gives physical data, and prices of the traps.

25 • APPLYING HEAT EXCHANGERS. For the engineer designing installations which will make use of heat transfer equipment, Patterson Foundry & Machine Co. has a new illustrated catalog on process applications of heat exchangers. Some 16 different types are described and illustrated, construction details, including tubes, codes, layout, shells, etc., are explained. Cost data are given, process applications, and information required for design, typical flow sheets of various process operations round out the book.

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26 • *BATCH CONTROL.* For controlling the amount of fluid going to a processing batch the Republic Flow Meters Co. has developed a new integrator control. A photoelectric cell, responding to reflections of a light beam mounted on a rotating integrator shaft, and an electric predetermined reset counter, act to measure a given quantity of fluid passing to the batch. Suggested for use in the chemical industries, it has already been used on the fluid charge to a pulp digester.

27 • *PIPING.* A descriptive data bulletin of the Michigan Pipe Co. covering wood stave pipe, wood-lined pipe, Saran rubber-lined pipe, stainless steel tubing, and monel metal tubing. Has tables of industries that the various kinds of types serve, the pipes resistance to chemical products, and individual bulletins on each type of pipe which give sizes, kinds of fixtures, weights, pressures ratings, etc.

28 • *FLOWRITE VALVE.* A series of diaphragm valves for pressures below 250 lb./sq.in. and sizes ranging from ¼ in. through 8 in. is described in a new publication of the Powers Regulator Co. A variety of valve bodies is available, single or double seat, reverse acting, 3-way. The diaphragm is molded Neoprene; cast iron body, special alloy steel springs, etc.

29 • *NOBLE METAL CATALYSTS.* A bulletin on noble metal catalysts covering platinum, palladium, silver, ruthenium, osmium, and iridium is a publication of the Johnson, Matthey & Co., Ltd., of England, but offered here by J. Bishop & Co., Platinum Works. The booklet covers use of platinum catalysts for ammonia oxidation, for the contact process, and for liquid-phase reactions. Palladium is covered as a hydrogenation catalyst, silver for the dehydrogenation of alcohol.

30 • *CORROSION RESISTANT PAINT.* Tygon plastic paints, series K and series TP are explained in a publication of the U. S. Stoneware Co. An extensive table on the chemical resistant characteristics of Tygon paint tells where and when not to use the material. Table of recommended primers and surface treatments and hints on how to get the best results to protect metal surface, application to other surfaces, technical data, etc.

31 • *HEAVY DUTY MOTORS.* Heavy duty d.c. motors for constant and adjustable speeds. Bulletin gives mechanical design, construction features, data for selection, dimensions, instructions for ordering. Reliance Electric & Engineering Co.

32 • *PINCH VALVES.* For handling highly abrasive solids-in-suspension or corrosive fluids, the Flexible Valve Corp. developed a line of natural and synthetic rubber pinch valves. These are described in a brochure covering applications, descriptions of all pinch valves, information on how valves operate. Tables with dimensions, list prices, etc.

33 • *PACKAGING METER.* A folder illustrates a packaging meter which automatically dispenses any preset quantity from 1 to 100 gal. for filling drums or other containers. The dial which is preset will return to zero after each delivery. Made by Bowser, Inc.

34 • *DEHYDRATING AGENT.* Filtrol Corp. four-page bulletin on the use of Desiccite, dehydrating agent. Used in the confectionery, pharmaceutical, food and chemical industry. Supplied in various sizes and various packages. Gives complete details, technical data, uses, etc.

35 • *ROTARY PUMP.* A De Laval bulletin on a new rotary pump for the chemical process industries. A general service screw-type pump designed for petroleum products and other light or viscous fluids. Capacities to 85 gal/min., pressures to 150 lb./sq.in. Complete details, technical data, dimensions, performance data, etc.

36 • *WATER PROBLEMS.* Hall Laboratories, Inc., in a brochure explain the services rendered for considering the complete water problem of an industry. Explains the organization of Hall technical staff, and how engineering specialists consider all the multiple water needs in an industrial process.

EQUIPMENT

40 • *STAINLESS STEEL VALVES.* Complete new line of stainless steel valves gate, check, and globe types,

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various weights and sizes which are now in production by Pacific Valves, Inc. For use in refineries, chemical plants, food, pharmaceutical, etc., where corrosion or metal contamination is a problem.

41 • ***HYDRAULIC LIFT DISSOLVER.*** Standard dissolvers for plant operations, but with the impeller raised and lowered hydraulically to clear the top of containers are new with the Cowles Co., Inc. Two models are in production. One bringing 15-40 hp. to the dissolving operation will lift 54 in. and swing through an arc so that containers can be set on the perimeter for continuous operation. The other model lifts 38 in. and brings 15 hp., 1800 rev./min. to the dissolving operation.

42 • ***PUMPING CONTROL.*** A control to start and stop pumps, increase or decrease the speed of one or more pumps, maintain a predetermined pressure at any point on a distribution system, automatically adjust pressure and flow to suit varying demands is a new development of Builders-Providence, Inc. The control consists of a flow-determining means, a pressure or level-sensing device and a mechanism to translate this information into a control function. Reduction of power costs, more efficient operation of pumps and elimination of station attendants are a few of the advantages claimed by the manufacturer.

43 • ***INDUSTRIAL COOLING FAN.*** A high efficiency axial fan for use in industrial installations, engine jacket water coolers for natural gas, gasoline, diesel engines, vertical air discharge condensing units, air and water coolers are new with the Koppers Co., Inc. The fans are produced on principles used in making automatic variable pitch aeroplane propellers. According to the manufacturer increased efficiency gives a 10% hp. saving. Sizes from 6 to 20 ft. in diameter, with the largest delivering half-million cubic feet of air per minute.

44 • ***VACUUM PUMP.*** A two-stage vacuum pump for dehydrating and testing refrigeration and air-conditioning units is a development of the Beach-Russ Co. Replacing an older model of the company, improvements have made it lighter and more compact with a faster pump down and vacuum. 1/3 hp. and weighing 80 lb., it is readily portable.

45 • ***FLOW METER.*** An electronic flow meter of the Potter Aeronautical Co. has been developed for use in chemical and industrial plants. It makes use of a rotor which spins within a venturi rotor and magnet spin within a nonmagnetic housing. An external pick-up coil connected to an electronic integrator or totalizer computes the flow. The sensing unit is available in sizes ranging from ¾ through 3½ in. Operating temperatures from 4° abs. to 1000° F. and housings withstand pressures up to 5000 lb./sq.in. Special housings can be supplied for pressures up to 20,000 lb./sq.in.

46 • ***JET SYPHONS.*** A 21-page catalog describing a full line of steam jet syphons made by Schutte & Koerting Co. It is in three parts covering the design, application, construction of operation of the syphons; special purpose and corrosion resistant syphons; and typical applications of steam jet syphons in the pumping, heating and mixing of liquids. Color drawings are used throughout the descriptive bulletin.

47 • ***GRINDING MEDIA.*** Nonmetallic ball mill grinding media, made of Borundum is announced by the U. S. Stoneware Co. The material is heavier and tougher than previous grinding media and resembles synthetic sapphire in composition. According to the company announcement they weigh 75-80% more and are up to 50% harder than conventional-type balls. They are in tubular shape to provide a greater contact area and are in the sizes 13/16 in. O.D. by 13/16 in. long. Performance data are available.

48 • ***OSCILLATING FEED.*** To distribute evenly and uniformly upon a conveyor, any loose, flaky, or granular material, Proctor & Schwartz, Inc., are making a hydraulically powered oscillating feed. Feed from a chute passes to the oscillating conveyor which deposits the material evenly and uniformly over a feed belt. It may be manufactured in various sizes according to customer needs. Hydraulic power gives a simple and accurate control speed and oscillation travel.

49 • ***UNIVERSAL STEAM TRAP.*** Velan Engineering Co. is making a steam trap interchangeable through various sizes of piping containing an integral strainer, glass inspection port, check valve and air vent. Bulletin available which explains the features and fundamentals of this and other steam traps.

50 • ***VARIABLE SPEED DRIVE.*** The Link-Belt Co. has a new line of automatic speed controls for the variable speed drive that it manufactures. The new control is available in four basic types—electronic, hydraulic, pneumatic and mechanical. A new bulletin illustrates the controls and how, with the variable speed drive, it automatically controls eight sizes of machines—from 1 to 25 hp. with speed ratios of 6:1.

51 • ***PORTABLE MIXERS.*** A new model portable mixer with plain and direct drives, and geared types in ¼, ½ and ¾ hp. sizes, is described in a new bulletin from The Patterson Foundry & Machine Co. Bulletin shows agitators plus dimensions and sizes, rev./min. from 420 to 1725 available with both open and explosion-proof motors. Adjustment makes the mixers adjustable to any angle of operation—vertical or sidewise.

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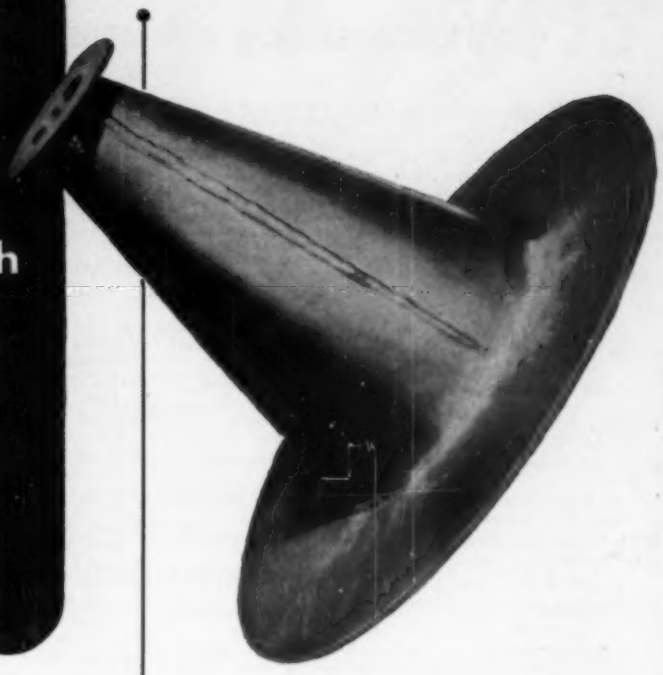

Used to introduce chlorine gas into a chlorinator at 100 deg. F., these HASTELLOY alloy reducers are still in operation after one year's service. The material previously used, iron-silicon alloy castings, failed because of poor mechanical strength.

The cost of each HASTELLOY alloy reducer has been about seventy cents a day, based on actual performance records to date, and since the reducers are still in service the final cost figure will be even lower.

The reducers were fabricated from HASTELLOY alloy C sheet. Ten-gage sheet was cut to size, rolled in the shape of a cone, and then welded to form the body. The top and bottom flanges were circle-cut from 12-gage sheet and then welded to the body. The assembly was then solution-treated to impart maximum corrosion resistance. All welds were made with a HELIARC torch using alloy C bare drawn wire.

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E. which states:

Election to membership shall be by vote of the Council upon recommendation of the Committee on Admissions. The names of all applicants who have been approved as candidates by the Committee on Admissions, other than those of applicants for Student membership, shall be listed in an official publication of the Institute. If no objection is received in writing by the Secretary within thirty days after the mailing date of the publication, they may be declared elected by vote of Council. If an objection to the election of any candidate is received by the Secretary within the period specified, said objection shall be referred to the Committee on Admissions, which shall investigate the cause for such objection, holding all communications in confidence, and make recommendations to the Council regarding the candidate.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before *Oct. 15, 1950*, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st St., New York 17, N. Y.

APPLICANTS FOR ASSOCIATE MEMBERSHIP

Richard D. Boutros, *Rochester, N. Y.*

Peter P. Chevis, *Pullman, Wash.*

W. H. DeLany, Jr., *Pittsburgh, Pa.*

Chuk Ching Ma, *New Orleans, La.*

APPLICANTS FOR JUNIOR MEMBERSHIP

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Fred J. Attaway, Jr., *Baton Rouge, La.*

John A. Banik, *Grand Forks,, N. D.*

George E. Barker, *Detroit, Mich.*

D. M. Beaty, *Waynesville, N. C.*

Jack H. Bergman, *Waynesboro, Va.*

John Samuel Betley, *Ambridge, Pa.*

Wayne C. Brock, *Brooklyn, N. Y.*

Donald H. Buchanan, *Collingswood, N. J.*

Salvatore Campanella, *Rome, N. Y.*

Thomas R. Campbell, *Lancaster, Ohio*

Mario F. Cangemi, *Albany, N. Y.*

James John Carberry, *Notre Dame, Ind.*

Leo A. Chabot, *Fall River, Mass.*

Richard C. C. Chang, *E. Syracuse, N. Y.*

J. Frank Cheely, *Baton Rouge, La.*

Robert C. Clarke, *McDonald, Pa.*

Vyvyan Stanley Clift, *Los Angeles, Calif.*

John W. Colbert, *Ottawa, Ont.*

Mike G. Collins, *Charleston, W. Va.*

Orrin K. Crosser, *Kent, Ohio*

Louis L. Czyzewski, *Chicago, Ill.*

Paul T. Davis, *Seminole, Okla.*

Kenneth D. Downing, *Detroit, Mich.*

W. Bruce Drinkhouse, Jr., *Easton, Pa.*

Robert A. Ebel, *Oak Ridge, Tenn.*

Garner D. Farrell, *Jackson, Mich.*

Norton D. Fern II, *Bala-Cynwyd, Pa.*

Mark B. Fries, *Dover, Del.*

Stanley T. Gadomski, *Pittsburgh, Pa.*

Gerald N. Gilbert, Jr., *W. Reading, Pa.*

John M. Gilmore, *Akron, Ohio*

Thomas R. Gleason, *Sayreville, N. J.*

Robert W. Hanak, *Kenosha, Wis.*

Gordon L. Hanks, *Warren, Pa.*

John J. Harris, *Houston, Tex.*

Donald R. Hecox, *E. St. Louis, Ill.*

Arthur W. Helwig, *Kirkwood, Mo.*

Hugh B. Henderson, *Long Beach, Calif.*

George O. Herold, *Phila., Pa.*

Arthur E. Hoffman, *Long Island City, N. Y.*

Byrd Hopkins, *Indian Orchard, Mass.*

Russell A. Ibson, *Montreal, Que.*

Robert B. Jagers, *Detroit, Mich.*

Bazle Karim, *East Pakistan, India*

Arnold Kaufman, *New York, N. Y.*

Ray G. Kehn, *Orange, Tex.*

Jack Keller, *Galveston, Tex.*

Emerson W. Kelly, Jr., *Stillwater, Okla.*

Ralph C. Kersten, *Detroit, Mich.*

Krishna K. Khandelwal, *Iowa City, Iowa*

Leonard Krawitz, *Brooklyn, N. Y.*

Joseph C. Landwehr, *New Orleans, La.*

Robert M. Latimer, *Newport, Ky.*

Ralph P. Levey, Jr., *Oak Ridge, Tenn.*

Robert A. Longmire, *Baton Rouge, La.*

Charles F. W. Luecke, *St. Louis, Mo.*

Richard Lynn McCall, *Huntingdon, Pa.*

John H. McCarthy, *Baton Rouge, La.*

Donald C. McGehee, *Detroit, Mich.*

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Irving Moch, Jr., *New York, N. Y.*

Elbert E. Moore, Jr., *Baton Rouge, La.*

A. H. Peters, Jr., *Mt. Pleasant, Tex.*

James L. Potter, *Gibson Island, Md.*

John J. Pytleski, *Lawrenceburg, Ind.*

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SECRETARY'S REPORT

S. L. TYLER

THE Executive Committee met in the offices of the Institute Aug. 11, 1950.

They approved the Minutes of the Executive Committee meeting of July 7, the Treasurer's report and bills for the month. They proceeded with the approval of the election of those listed in July C.E.P. providing no adverse comments were received from the membership and as none were received prior to the closing date, Aug. 15, those listed were elected to the grades of membership indicated.

Robert R. Rothfus was appointed counselor of the student chapter at Carnegie Institute of Technology to succeed C. C. Monrad.

The Committee received a report from the Awards Committee giving the names of the recipients selected to receive the Professional Progress Award in Chemical Engineering, the William H. Walker Award and the Junior Award; a complete announcement will be made.

Harry McCormack was appointed as representative of the Institute to attend the annual meeting of the National Council of State Boards of Engineering Examiners in Chicago, Oct. 9-11, 1950.

Six resignations from membership were received and accepted.

N. D. Steele was appointed a member of the Local Sections Committee representing the Texas Panhandle Section and R. G. Rhodes to the Public Relations Committee representing the same section.

At the request of the Power Test Codes Committee of the A.S.M.E., H. F. Newman was appointed on its subcommittee on Centrifugal and Rotary Pumps.

It was reported that the Institute had been invited to participate in the Centennial of Engineering, 1952, to be held in Chicago, celebrating the 100th Anniversary of the founding of the A.S.C.E. and that President W. L. McCabe had been appointed a member of the board of directors of the Centennial. An exhibition at the Chicago Museum of Science and Industry is planned which will stress the importance of engineering in all walks of life; the Institute will appoint an advisory committee to work with those arranging for these exhibits.

The budget for 1950 was reviewed in the light of six months' experience and a projection of probable expenditures for the balance of the year. It was thought to be in order and showed that the Institute was operating within its income.

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5. **AUDIO-ALARM SYSTEM:** Permits remote operation. Variable pitch of the alarm is proportional to the size of the leak.

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MARGINAL NOTES

(Continued from page 24)

Combining Practicalities With Theory

Industrial Electrochemistry. Third Edition. C. L. Mantell. McGraw-Hill Publishing Co., New York. (1950) 752 pp. $8.50.

Reviewed by Marvin J. Udy, Consulting Engineer, Niagara Falls, N. Y.

IN THIS new edition Dr. Mantell has greatly increased the data and information over that contained in the original 1931 and 1940 editions. The number of pages has been increased to 752 from 501. By careful selection of data and arrangement Dr. Mantell has been able to allow much of the old to remain and to bring in new material from the developments of the past 20 years.

The book, well balanced between the theoretical and the practical, is designed for the practical chemical engineer as well as for the student. The expanded theoretical data in chapters 1 to 6 are adequate for most purposes where sound engineering application is involved and also for most theoretical problems. In the chapters covering primary and secondary cells, the electrorefining of metals and the electrowinning of metals, the practical applications and data are of value to both engineer and student. Likewise, the chapters on the electrolysis of alkali halides and sulfates and the electrolysis of fused salts contain much valuable data.

In the division on electrothermics, Dr. Mantell has condensed a wealth of material into a small number of pages. This division covers the electric furnace in the production of steel, foundry metals and alloys, calcium carbide, calcium cyanimide, ferrosilicon, ferromanganese, ferrochromium, ferrotungsten, ferromolybdenum and many other alloys, as well as phosphorus and ferrophosphorus. The data are general, but are about the best available for these industries.

There is nothing in the volume concerning electromagnetic and electrostatic separation of minerals. Electromagnetic processes are in use in many industries, notably of recent date in the sink and float process for the recovery of ferrosilicon and magnetite from the flotation process. Whether electromagnetic separation or electrostatic separation can be classified as an electrochemical process or not is a matter of opinion. It would seem, however, that it would have a place in a book of this character. Electrostatic precipitation is well covered. All in all the volume is well done. Dr. Mantell has had many of the foremost men in the industry supply important data and review and criticize the chapters and material.

How Apt Is the Scientist?

The Development of a Test for Selecting Research Personnel; Man-Power Branch, Human Resources Division, Office of Naval Research; American Institute for Research, Pittsburgh, Pa.

Reviewed by M. G. Shepard, Development Manager, Naugatuck Division, U. S. Rubber Co., Naugatuck, Conn.

THIS is a report in pamphlet form of the second in a series of projects being studied under the sponsorship of the Office of Naval Research by the American Institute for Research. The Institute has undertaken for the Office of Naval Research to conduct an investigation the purpose of which is to develop more adequate methods for the selection and evaluation of scientific personnel for research and engineering work. The entire program consists of five steps as follows:

1. Determination of the critical requirements for successful participation in research and engineering work
2. Development of an aptitude test for the selection of scientific personnel
3. Development of tests to measure proficiency in specific areas of scientific work
4. Development of procedures for evaluating the job performances of scientific personnel
5. Determination of the predictive value of the tests developed in steps (2) and (3) using the procedures developed in step (4) to obtain evaluations of personnel for comparison with test predictions.

The present report is a description of the procedures used in the development of the aptitude test required for the fulfillment of step (2); the first step was completed as an earlier project. The report states the objectives: to develop test items needed to predict the behavior of the subject in regard to certain critical factors indicated to have a bearing on the requirements for successful participation in research and engineering work brought out by the studies made under step (1) of the long-range program. The methods of development of the test items are described in considerable detail and some specific examples are given.

This report should be of interest to anyone concerned with the development of aptitude tests for scientific personnel. When the entire long-range program is completed it should be of interest to research and personnel directors or others having anything to do with selecting and evaluating scientific personnel. It is to be hoped that the work being undertaken by the Office of Naval Research will accomplish something really worth while in this direction.

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(*News cont. from page 20*)

STEVENS INSTITUTE TO TEACH MARKETING

Industrial employees and engineering students will be taught how to market the products of industry in new marketing and research courses to be given this fall by the Graduate School of Stevens Institute of Technology, Hoboken, N. J.

Courses have been arranged so that students will get a good idea of all the opportunities in the distribution field and be better prepared to advance in such positions. Industrial marketing will be presented as including research, advertising, sales administration, service, policies, product design and packaging, and application engineering, as well as industrial salesmanship.

With more than 50 cents of every consumer dollar going to distribution, it is vital to the economy to find the most efficient methods of distribution, just as engineers have increased efficiency in production through time studies and other methods, it was explained today by Prof. Calvin H. Brainard, of the Stevens faculty, who planned the courses.

Most of the classes will be given in the evening by full-time faculty members or lecturers connected with related businesses. There will be some day-time classes open to advanced undergraduate students as well as graduates.

CHEMICAL CONFERENCE FOR SOUTH

Plans have been announced for a Southwide Chemical Conference to be held at Atlanta, Ga., Oct. 16 to 18. News of the regional conference, second of its type and largest ever to be held in this area, was released by a joint committee of the American Chemical Society and the Southern Association of Science and Industry. The two organizations are acting as joint sponsors of the meeting, which is designed to accelerate Southern progress in all fields of chemistry.

Special technical sessions will be devoted to physical, inorganic, organic, and analytical chemistry, biochemistry, chemical education, and industrial chemistry. A chemical industries session will occupy one full day of the program, with reports on opportunities for plastics industries, expansion of petroleum industries, quality control in food and drink industries, and development of new chemical products from Southern raw materials.

A copy of the complete program for the Southwide Chemical Conference, data on reservations, and other information on the meeting may be obtained from SASI Headquarters, 5009 Peachtree Road, Atlanta.

MANAGING TECHNICAL OPERATIONS

(*Continued from page 12*)

Marketing New Products

Let us assume that we are on the management level of a chemical company with the problem in cooperation with production and sales executives of determining the course of action that should be taken on the manufacture of a new chemical somewhat foreign to our normal line of business. The first problem is to determine our production excellence. Do our research, our development, our engineering, our construction, and our production divisions have the necessary experience, the necessary ability to handle this new chemical. In other words can we do the job well. Second, we take a look at our sales competence. Does our advertising department know how to handle the advertisement of this particular type of specialty product. Are we set up for the proper trade promotion. Do we know the trade practices in this field. Do our selling techniques fit in with the established practices in the market that this chemical must meet. Can we interest others permanently in what we can do.

Third, we endeavor to determine the economic soundness of our proposition. What is our present technical status on the development of this new chemical. What is our raw material situation. What will be our production problem. What will be our cost of producing and our cost of selling. Finally, what is the legal situation surrounding this new chemical. In other words we determine shall we do it at all.

What our assignment boils down to is asking ourselves annoying questions and then finding the answer. Often a particularly annoying question is "why should we, rather than some other company try to do this job?" If this other company makes materials we have to buy in order to do our job what will we do if it decides to compete? How many chemical routes are there for making this new chemical? Are some other ways inherently superior to ours?

A difficult question is the estimation of our present or planned position versus the actual or potential position of our existing or possible future competition. We always must remember that competition is dynamic. There is no final outcome, its merely the relative position in many races. In the final analysis this relative position is determined entirely upon who can give the greatest value to customers.

Of all the questions we ask, those questions dealing with the economic soundness of our problem are the most critical. It doesn't help to make the chemical well or to make skillful public offerings if it shouldn't be done in the first place. These questions on economic soundness invariably center around what might be termed the market situation. If this chemical that is new to us is old in the sense that it is an established chemical then we must determine on what basis we can become a supplier. Is the supply of the chemical short or can we improve the quality to a significant degree because we have an improved process. Or can we simply produce and sell a product competitive quality-wise but at a reduced price because we have an improved process or a special raw material situation. If our chemical is an entirely new one why should any one want to make it. Just how much time and money are required to determine the interest in this new product of ours and as a corollary to that question

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5. Production chart for the past 20 years.
6. Generalized use pattern.
7. Price chart for the past 20 years.
8. Miscellaneous data, including physical properties, commercial grades, shipping regulations, and usual containers.
9. Economic aspects, generally including historical data, a discussion of competitive products and processes, recent trends in manufacturing and sales, actual and economic plant size, and approximate plant cost.
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how much time and money can we afford to gamble. Whether the chemical is new or old can we make it enough cheaper than both today's and tomorrow's actual probable selling prices to pay for doing the job and still have something left over for next year's job.

Analysis of Market

The techniques of market analysis are still in an embryonic stage. Since its objective is to expand sales volume, it is too frequently confused with sales promotion. Market analysis should be the collecting and analysis of the significant technical and economic background facts that are pertinent to the company's present and planned operations. I believe that in order to have an unbiased market analysis group, rather than a sales promotion group, it should be independent of the sales division. Probably the best arrangement is for the market analysis group to be entirely a staff function.

In our company in the technical organizations we start planning operation at the development supervisor level which is our title for the development group leader. When the research chemist turns over to the development division a small sample of a new chemical with a suggested process the first step is to determine the probable manufacturing cost of this chemical. This is done by taking the research yields and determining the total raw material cost which includes any extra materials or royalty payments. A probable flow sheet of the process is sketched roughly and by using what is essentially Chilton's method, plant equipment costs are determined. The building and utility costs are determined on the basis of our experience at different plant locations. From this plant cost we determine amortization breaking this down into floor space expense, machine depreciation, taxes, and insurance. The direct and indirect labor is estimated and the various departmental supplies such as steam, electric power, refrigeration, water, machine maintenance, plant cleaning and minor alterations are also estimated. To these costs we add a charge for development and research expenses, a charge for warehousing and shipping, as well as any transportation cost. If this new chemical is to be sold outside our company a figure based on experience is assumed for commercial overhead. Having the total cost of our product we then in cooperation with the sales department assume a selling price. Having cost, selling price, and working capital, the annual new earnings or savings are determined and the annual return after taxes on total capital as well as the profit per sales dollar is calculated.

Obviously, the calculation of costs before manufacturing development is even started is subject to considerable error. However, we do feel that it at least gives us the information necessary to determine whether we can play in the same ball park as our competitors.

If we decide to go ahead with the manufacturing development of our new product then the technical phases of the problem are reviewed by the group leader with the manager of the experimental station on a weekly basis. Costs of carrying on the work are reviewed monthly. Periodically the group leader submits a chart of his progress by giving his current thinking on the questions detailed below.

Chart of Progress

1. What is the New Product?
   a. In what sense is it new?
   b. Why do we wish to introduce it?

c. Who will buy it?
d. What is the market in volume and price history?
e. What is the competition?
f. How should it be promoted and sold?
g. How should the new product be packaged?
h. Are customers now equipped to handle our new product?

II. Raw Materials Situation

a. Are raw materials readily available?
b. How many sources of supply?
c. Does supplier need to build facilities to supply our needs?
d. Should we develop our own raw materials?
e. What would be involved to so do?

III. Present Status of Development

a. What difficulties have been solved?
b. What difficulties remain?
c. When do you think development could be finalized?
d. How could development be speeded?
e. Do you feel further improvements can be made?
f. Are you satisfied with evaluation testing?
g. If work has not started, how important do you think a high priority on the work is?
h. What experimental station, laboratory, or production plant should do the development and why?

IV. Production

a. Can the product be made in an existing plant?
b. What changes in an existing plant are needed?
c. What would a new plant be like?
d. What production difficulties do you foresee?

V. Cost

a. What will a new plant cost?
b. How many years should be allowed for amortization?
c. What is the materials cost?
d. What do you think direct labor will cost?
e. What do you think indirect labor will cost?
f. What do you think utilities will cost?
g. What is the calculated production volume at which profit occurs?

VI. Legal

a. Is ownership of the new product established?
b. What patent disclosures have been submitted?
c. Are competing patents in existence?
d. Do government regulations on health or safety restrict production or sale of the new product?
e. Is special labeling required?

While the group leader's answers to these questions are valuable to the management planning group their chief value is in helping the group leader plan intelligently on a commercial basis his own development program.

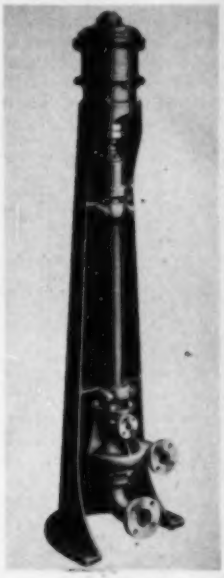
Further, we want to develop technical personnel to be future sales, production and technical executives.

Only those technical organizations that are staffed by men who combine business judgment with their technical skill can perform satisfactorily in competitive industry.

(Address given before Pittsburgh Local Section, A.I.Ch.E.)

(Right) **Structural details of Lawrence Vertical Acid Pump.**

(Below) **Vertical Acid Pump for outside mounting.**



VERTICAL ACID AND CHEMICAL PUMPS

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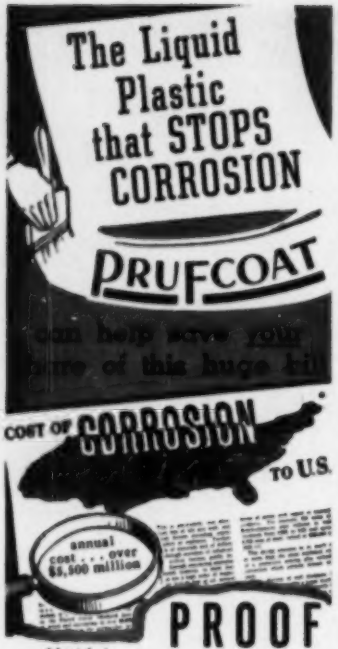
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LOCAL SECTION NEWS

TIDEWATER VIRGINIA CHEMICAL ENGINEERS' CLUB

A representative group of chemical engineers from the Richmond-Hopewell Petersburg area has formed the Tidewater Virginia Chemical Engineers' Club following a preliminary meeting held late last year in Richmond and a subsequent one at which 40 people were present. Officers and directors elected for the current year are as follows:

President—R. E. Clark, DuPont Co., Richmond, Va.
Vice-President—R. L. Baber, Solvay Process Co., Hopewell, Va.
Secretary—R. W. Nash, Du Pont Co., Richmond
Treasurer—P. E. Graybeal, Hercules Powder Co., Hopewell
Directors (in addition to the officers): W. D. White, H. K. McKenzie, R. B. Arnold, M. J. Bogese

The first program meeting of the club was held June 14, 1950, near Hopewell. After a reception, dinner and short business meeting 53 members and guests heard W. E. Pratt, chemical and corrosion consultant for Worthington Pump and Machinery Corp., speak on "Corrosion."

Three additional meetings are planned for this calendar year.

Reported by R. B. Arnold

MARYLAND

The first meeting of the 1950-51 program of this section will be held Oct. 10 at the Tap Room of the Johns Hopkins Faculty Club. The speaker will be Guy N. Harcourt of the Blaw-Knox Co., who will discuss "Vacuum Drum Drying."

Reported by Alan Beerbower

OKLAHOMA

This section held a joint meeting with the N.E. Okla. section of the A.C.S. July 13 at the Phillips Apartment Hotel in Bartlesville. Approximately 130 members and guests attended. Dr. Kenneth M. Watson spoke on "High Pressure Vapor-Liquid Equilibria in Hydrocarbon Systems." Dr. Watson reviewed past and current work on idealized vaporization equilibrium ratios.

Reported by George E. Hays

WINNER OF CECIL TROPHY AWARD IN TULSA

J. E. LATTA E. C. CARLSON

Eugene C. Carlson has been selected as the recipient of the first annual Cecil Award presented by Tulsa Section of A.I.Ch.E. He was selected from among five men who competed for the award during 1949. His paper, "Octane Requirements of Present and Future Automotive Engines," was presented at the September, 1949, meeting of the section. Here J. E. Latta, chairman of the awards committee, is presenting the trophy.

This award is known as the Cecil Trophy and was donated by L. K. Cecil of Infilco, Inc., who was one of the founders of the Tulsa Section. The competition was initiated in order to arouse interest among young engineers in A.I.Ch.E. and to familiarize them with the problems of preparing and presenting technical papers. Contestants are rated upon delivery, timing, appearance, enunciation, organization of material, quality of slides and knowledge.

SOUTHERN CALIFORNIA

At its monthly dinner meeting Aug. 15, 1950, at Scully's Restaurant in Los Angeles, 80 members and guests were present. Dr. Olaf A. Hougen, professor of chemical engineering, University of Wisconsin, and visiting professor of chemical engineering at the University of California, was the guest speaker and his subject was "Exploratory Methods in Thermodynamics."

Dr. Hougen presented exploratory methods in thermodynamics calculations, which are of special value for use in engineering, where experimental data are not complete or where extensive computational services are either unavailable or unwarranted. These methods are a particularly useful tool for the process engineer as a guide for experimental work and as a preparation for more precise calculations. Examples were presented dealing with the construction of various thermodynamic tables and charts for problems dealing with power and heat requirements, vapor-liquid equilibria, and catalytic conversion.

The July dinner meeting was held on the eighteenth, at the Elks' Temple in Los Angeles with some 75 members and guests present. The section's guest and speaker was Dr. Warren McCabe, President of A.I.Ch.E., who discussed "The Institute—1950 model." Special emphasis was given to the growth and service of *Chemical Engineering Progress*.

Of historic interest to this section, J. G. Dean, who has been a member of the Institute since 1908, presented a picture of the Twelfth Semi-Annual Meeting of A.I.Ch.E., which was held in Montreal in 1920. Many prominent members of the Institute, including a number of national officers were identified by Mr. Dean and Dr. McCabe.

Reported by William J. Baral

COASTAL GEORGIA CHEMICAL ENGINEERING CLUB

The second meeting of the chemical engineers in the coastal Georgia section was held July 14 in Savannah. A total of 56 persons attended from Savannah, Brunswick, and Charleston, S. C.

A. R. Bookout of Hercules Powder Co., Brunswick, gave an interesting talk on the high pressure laboratory at the Hercules Experiment Station, Wilmington, Del.

Following Mr. Bookout's speech a short business meeting was held. At this meeting it was decided to hold the next meeting of the organization in Brunswick Sept. 15.

Reported by E. O. Barnes

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George E. Holbrook

Room 7406 Nemours Bldg.,
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Wilmington, Del.

MEETINGS

Annual—Columbus, Ohio, Neal House, Dec. 3-6, 1950.

Technical Program Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio

Regional — White Sulphur Springs, W. Va., The Greenbrier, March 11-14, 1951.

Technical Program Chairman: Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York, N. Y.

Regional—Kansas City, Mo., Hotel Muehlebach, May 13-16, 1951.

Technical Program Chairman: Walter W. Deschner, J. F. Pritchard Co., Kansas City, Mo.

Annual — Atlantic City, N. J., Chalfonte-Haddon Hall Hotel, Dec. 2-5, 1951.

SYMPOSIA

Air and Water Pollution Control

Chairman: Richard D. Hoak, Mellon Institute of Industrial Research, University of Pittsburgh, Pittsburgh, Pa.

Meeting—Columbus, Ohio

Chemical Engineering in Glass Industry

Chairman: F. C. Flint, Hazel-Atlas Glass Co., Washington, Pa.

Meeting—Columbus, Ohio

Processing of Viscous Materials

Chairman: W. W. Kraft, The Lummus Co., 420 Lexington Ave., New York, N. Y.

Meeting—Columbus, Ohio

Phase Equilibria

Chairman: W. C. Edmister, Carnegie Inst. of Tech., Pittsburgh, Pa.

Meeting—Columbus, Ohio

Relationship Between Pilot-Scale and Commercial Chemical Engineering Equipment

Chairman: Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York, N. Y.

Meeting—White Sulphur Springs, W. Va.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, George E. Holbrook, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

NEW ORLEANS

The speaker for the Sept. 7 meeting of this section at the St. Charles Hotel was C. F. Prutton, vice-president and director of operations of the Mathieson Chemical Corp. He discussed commercial applications of chlorine dioxide of comparatively recent date. These include its application as a bleaching agent in the pulp and paper industry, as a decolorizing agent to up-grade fats and oils and as a deodorizing agent for municipal water supplies.

Of particular interest to Louisiana engineers is the final passage of a registration law for all engineers. This law will become effective as soon as the new board works out the administrative details.

Reported by Ralph M. Persell

NORTHERN CALIFORNIA

At the July meeting held at El Curtola Restaurant in Oakland, attendance was 100.

Warren L. McCabe, vice-president in charge of research, Flintkote Corp., and President of A.I.Ch.E., talked on the

Institute and its sections. Dr. McCabe discussed the organization and functions of the committees, finance and other problems, and the dependence of the national society on the size and activity of its membership. Pointing out that the total membership is now more than 10,000 he estimated on the basis of the growth curves for societies of other branches of engineering that all tend to level off at about 25,000 members.

Reported by J. V. Hightower

SOUTH TEXAS

The regular monthly meeting of this section was held in Houston on July 14, 1950. No inspection trip was scheduled. Sixty-four members foregathered in the early evening to eat dinner at the Alabama Banquet Room and to hear an address by Prof. W. K. Lewis of M.I.T. Professor Lewis spoke on "Engineering as a Profession."

Reported by G. T. McBride, Jr.

INDUSTRIAL NEWS

(*Continued from page 32*)

NEW RESEARCH LAB. FOR STAUFFER

Stauffer Chemical Co. announced the construction of a new research and development laboratory at Dobbs Ferry, N. Y., to get under way at once. When completed, the building will house the research staff of the company's Eastern division now scattered at several locations in and around New York City. Five large laboratories for various research projects, administrative offices, technical library, workshop and storage and service areas will be provided. All rooms and laboratories will be air-conditioned and equipped with a wide variety of the most modern equipment.

Stauffer's Chauncey plant is located nearby and will furnish facilities for pilot plant testing of products and processes developed at the new laboratory. John F. Crowther, director of the firm's Eastern research division, will be in charge.

The Stauffer Chemical Co., 65 years old this year, operates 30-odd plants in almost every industrial area of the country. Other chemical research laboratories are located at Los Angeles and at Richmond (San Francisco), Calif., where Dr. Chester L. Arnold, director of the company's research and development department, makes his headquarters. The company also operates an agricultural chemical research laboratory at Los Altos, Calif.

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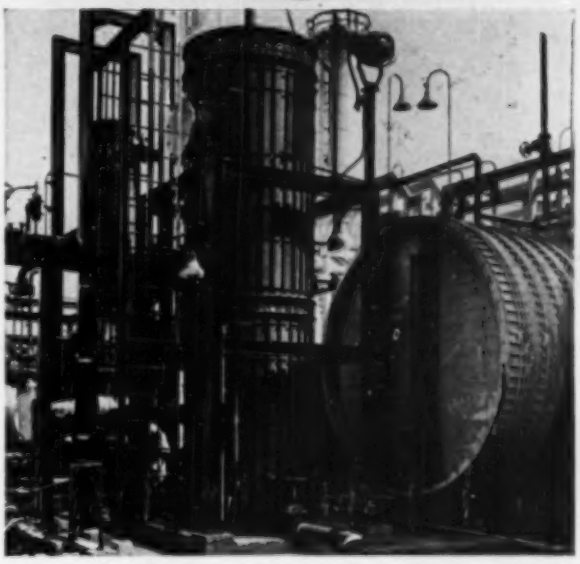

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PEOPLE

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E. W. VOLKMANN

E. W. Volkmann has been appointed an assistant manager of the research department of Koppers Co., Inc., Pittsburgh, Pa., with the responsibility for the laboratory and development sections.

Dr. Volkmann, a native of Germany, was graduated from the University of Koenigsberg with an M.E. degree in 1924. He then came to the United States, receiving his Master's and Doctor's degrees in chemical engineering at Columbia University and remaining here to become an American citizen. He joined a predecessor company of Koppers as a chemical engineer in 1926, but left to complete his postgraduate work. Subsequently he returned to Koppers as assistant technical director of its tar and chemical division in 1934 and has been associated with the research department since 1940.

NOW A CONSULTANT

ARNOLD BELCHETZ

Arnold Belchetz, formerly chief technologist for Shell Petroleum Corp. and later head of the new processes department, The M. W. Kellogg Co., is now practicing as a consultant to the petroleum and chemical industries. Dr. Belchetz was at one time director of research and development for Stauffer Chemical Co. His consulting offices are located at 125 Woodbine Avenue, Larchmont, N. Y.

CHANGES AT MONSANTO'S SPRINGFIELD PLANT

Eli Perry has been appointed an assistant director of research of Monsanto's Chemical Co.'s plastics division. Robert W. Jones has been appointed a group leader in the research department. Both are located in Springfield, Mass.

Mr. Perry, who has been a member of the research staff since his graduation from the University of Pennsylvania in 1942, was one of the first Monsanto employees to be selected under the company's program providing academic leaves of absence with full pay. He received an M.S. in chemical engineering from M.I.T. in 1947.

Mr. Jones was employed by the plastics division in 1946 after several years of service as an officer of the U. S. Navy. He is a graduate of the University of Michigan with a B.S. in chemical engineering and mathematics.

OLIN INDUSTRIES ACQUIRES J. B. WEAVER

James B. Weaver has been appointed technoeconomist in the commercial evaluation department of Olin Industries, Inc. Olin Industries is the parent of the Western Cartridge Co. and the Winchester Repeating Arms Co.

Weaver, a chemical engineer, attended the Massachusetts Institute of Technology where he received his Bachelor's degree in 1944 and his Master's degree in 1947. Prior to earning his Master's degree, Weaver taught in the chemical engineering department there.

From 1945-50 Weaver was with Godfrey L. Cabot, Inc., chemical manufacturers, both as pilot plant supervisor and as assistant to the director of research. He has had experience in chemical engineering and administration, research accounting and budgets, research reporting and chemical market research. His product experience has been mainly in the production and use of industrial chemicals, particularly carbon black.

W. C. Beekley, president of Whitlock Manufacturing Co., Hartford, Conn., was recently elected vice-president of the Tubular Exchanger Manufacturers Association, Inc. T.E.M.A. is an association of tubular exchanger manufacturers, formed several years ago for the purpose of establishing and maintaining highest possible standards in the design, fabrication and performance of shell and tube heat-transfer equipment

BECOMES CONSULTING ENGINEER

MAX LEVA

Max Leva, formerly with the U. S. Bureau of Mines as a project research leader, is now a consulting chemical engineer with headquarters at Pittsburgh, Pa. He is engaged in equipment and process development, design and technical writing. With the Bureau of Mines he worked on synthetic liquid fuels development and fundamental research in fluid flow, catalysis and heat transfer. Mr. Leva was associated at one time with Blaw-Knox Co., and Vulcan Copper & Supply Co., having done general engineering design, proposal work and pilot plant studies on alcohol, acetic acid and synthetic rubber projects. He holds a B.S. in chemical engineering from the University of Cincinnati and an M.S. in chemical engineering from the Carnegie Institute of Technology.

William M. Campbell, formerly an instructor in chemical engineering, University of Illinois, Urbana, is now associated with the Atomic Energy Project, National Research Council, Chalk River (Ont.), Canada.

David A. Trageser is now associated with Dewey and Almy Chemical Co., as a chemical engineer in the manufacturing department. He was formerly assistant professor in chemical engineering department, Massachusetts Institute of Technology, Buffalo Station school of chemical engineering practice.

Darrel E. Mack, professor of chemical engineering, chemical engineering department, Lehigh University, Bethlehem, Pa., has been appointed director of the curriculum in chemical engineering. Dr. Mack is a graduate of Purdue University and has been a member of the faculty at Bethlehem since 1945.

Donald D. Lee is now manager of the technical section of the Sabine River Works of Du Pont Co., Orange, Tex. Dr. Lee was formerly located at Charleston, W. Va., as assistant technical superintendent, technical section, Belle Works of Du Pont.

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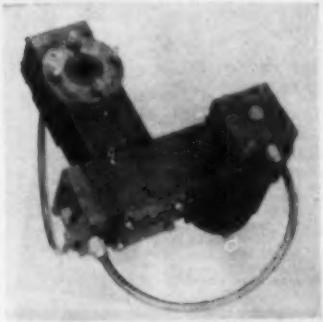

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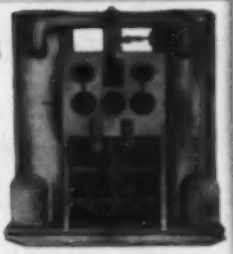

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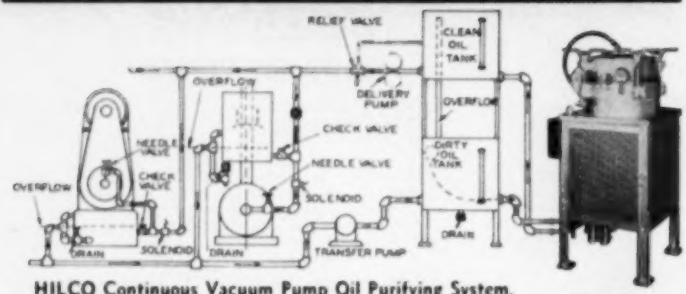

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GREBER, CHIEF ENGINEER FOR SCHENLEY

Arthur C. Greber, Cincinnati, has been appointed chief engineer of Schenley Distillers, Inc., according to an announcement by E. S. Monohan, vice-president. Associated with the distilling company's engineering department since 1943, Greber has been serving as engineering manager prior to this latest promotion. He succeeds E. S. Monohan as chief engineer, the latter formerly having held this title along with that of operations manager.

A. C. GREBER

According to the announcement, Greber will be responsible for all engineering work throughout the company's nation-wide organization of plants. This includes supervision of all design, construction and maintenance, and all engineering operation methods. His office will continue to be in Schenley's Cincinnati production headquarters.

A native of Cincinnati and a graduate chemical engineer of the University of Cincinnati, the appointee is a registered engineer in Ohio, Indiana, Kentucky, Pennsylvania and Maryland. He is secretary of A.I.Ch.E. Ohio Valley Section, and a member of several engineering societies.

M. E. Krigel is now vice-president of the Monark Egg Corp., Kansas City, Mo. He was formerly with Associated Laboratories, Dallas, Tex., as industrial chemist.

C. W. Hardell, formerly associated with the Sinclair Refining Co., Wellsville, N. Y., is now general superintendent of the Sinclair Rubber Inc., Houston, Tex.

Clayton J. Sandel, formerly plant superintendent, Tantalum Defense Corp., North Chicago, Ill., is now plant manager of The Electrical Equipment Engineers Co., Melrose Park, Ill.

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LAPPLE, SYVERSON GO TO OHIO STATE

Charles E. Lapple of Wilmington, Delaware, and Aldrich Syverson of Syracuse University have been appointed associate professors in the department of chemical engineering at Ohio State University. An announcement to this effect was made recently by Dr. Joseph H. Koffolt, department chairman.

Professor Lapple, whose appointment will become effective Oct. 1, has been associated with the engineering research laboratory of the Du Pont Co. in Wilmington since 1937, where he specialized in dust collection, atmospheric pollution abatement, aerosols, size classification and fluid mechanics. In 1946 he received the Junior Award of the American Institute of Chemical Engineers.

A graduate of Columbia University, Lapple holds both the bachelor of science and the chemical engineer degree from that institution. He has also taught graduate courses at Columbia and at the University of Delaware.

Dr. Syverson was associate professor of chemical engineering at Syracuse University from 1948 until joining the Ohio State staff this summer. He received the bachelor of chemical engineering and doctor of philosophy degrees at the University of Minnesota. From 1942 to 1948, he was affiliated with the B. F. Goodrich Chemical Co., holding the position of plant manager at the Avon Lake Experimental Station.

OBERFELL RETIRES FROM PHILLIPS PETROLEUM

G. G. Oberfell, a member of the board and executive committee, as well as vice-president of research and development of the Phillips Petroleum Co. Bartlesville, Okla., recently retired from active duty under the provisions of the company's retirement plan.

Mr. Oberfell started with the company a quarter of a century ago and established the research department, which became under his direction "one of the most outstanding in the oil industry." He is a recognized authority on petroleum research, especially in the fields of natural gasoline, natural gas and lighter hydrocarbons. Prior to his association with Phillips Petroleum, Mr. Oberfell was associated with several other enterprises, namely the Bureau of Mines, the Ohio Fuel Supply Co., and the Hope Engineering & Supply Co. He received a Bachelor's degree in chemistry from Miami University, Oxford, Ohio, and also studied at Chicago University and University of Pittsburgh.

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CARPENTER PROMOTED BY DU PONT CO.

W. Samuel Carpenter, III, who began working for the Du Pont Co. as a summer-replacement chemist's helper back in 1934, has been appointed assistant manager of the rayon department's planning division. J. N. Tilley is manager of the division.

A graduate of Princeton University, where he received a degree in chemical engineering in 1938, Mr. Carpenter began his regular employment with the company as a junior industrial engineer in the fall of that year. From May, 1940, until June, 1942, he was in the nylon division working as a production planning assistant at the Seaford (Del.) plant and at the company's offices in Wilmington.

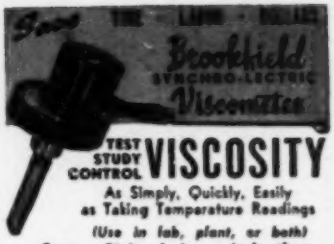
For five years, beginning in June, 1942, Mr. Carpenter was a member of the engineering department, working in the industrial engineering and construction divisions. During a portion of this period in 1944, he was assigned to the government's atomic energy project at Hanford, Wash.

In April, 1947, Mr. Carpenter was made assistant to the director of production of the rayon division, and subsequently became assistant sales manager of Cordura high-tenacity rayon yarn. Since January, 1950, he has been acting manager of the planning section of the rayon division.

James T. Costigan, district manager of the Sharples Corp., has been elected alumni representative on the board of trustees of Stevens Institute of Technology, Hoboken, N. J. Since his graduation from Stevens in 1933 Mr. Costigan has been active in alumni affairs of the college. Besides the degree of M.E. from Stevens Institute, Mr. Costigan has an M.S. from Columbia University, and an LL.B. from Fordham Law School. In 1946 he received the degree of professional engineer from the University of the State of New York. He is a member of many technical societies.

Edwin F. Pike, chemical engineer consultant, has joined Wallace Clark & Co., Inc., management consulting firm of New York, N. Y. Dr. Pike has broad experience in research and development, engineering, manufacturing and technical operations in the food, fine chemicals, and pharmaceutical fields. In his new post he will act as special consultant on work for clients in the chemical industry.

Otto B. Vogel has joined the Boston Consolidated Gas Co. as superintendent of customers' service division. Before this, Mr. Vogel was adviser for the Phillips Petroleum Co. at Landing, N. J.



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CHANGES IN STANDARD OIL (IND.) SETUP

A number of organizational changes were announced recently for the research department of the Standard Oil Company (Indiana). Some of these changes affect members of A.I.Ch.E., such as A. O. Conn who was named division director of pilot plants and Nathan Fragen who was appointed division director of all research activities in the field of chemical products. Previously Mr. Conn was section leader of the pilot plant division in the research department, and Mr. Fragen was assistant director of research.

Others well known in the chemical engineering field and mentioned in the changes are E. W. Thiele and E. W. Adams. Both were made associate directors of research.

Dr. Thiele joined Standard's research staff in 1925 and became assistant director of research in 1935. During 1942 and 1943 he was on leave of absence, working with the Office of Scientific Research and Development on war assignment.

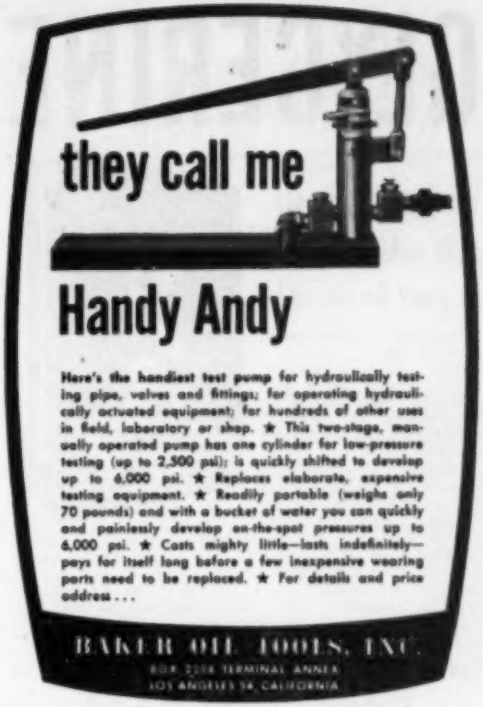
Dr. Adams joined Standard in 1925 and became assistant director of research in 1945.

Ralph E. Montonna, formerly director, Institute of Industrial Research, Syracuse University, Syracuse, N. Y., is now associated with the University of Minnesota, Minn., in the Engineering Experiment Station.

H. Roswell Jones was recently appointed to the synthetic fuels and chemicals department of the chemical plants division of Blaw-Knox Construction Co. He will be engaged mainly in the design of plants to produce finished refined products from Fischer-Tropsch, Oxo, and Oxyl syntheses. Previously, Dr. Jones had been technologist in the manufacturing department of Continental Oil Co., Ponca City, Okla.

Bradley Dewey, Jr., has been appointed manager of the Cryovac division of the Dewey and Almy Chemical Co., Cambridge, Mass. Dr. Dewey will head up the sales, manufacturing, and research activities of the division, which manufactures Cry-O-Rap bags and tubing from a special Dewey and Almy-Dow (Saran) plastic for use in the packing of frozen and refrigerated meats and other foods.

John W. Kenney recently joined the staff of the chemistry and metallurgy division of the Los Alamos Scientific Laboratory of the University of California, Los Alamos, N. M. His title is junior safety engineer. He was formerly with the Army Chemical Corps in Tooele, Utah.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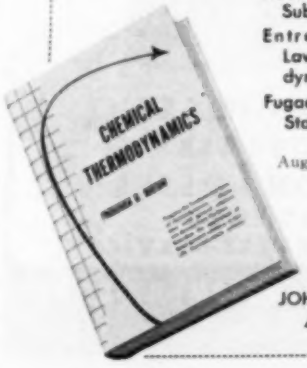

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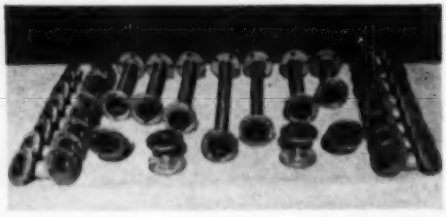

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William S. Shaw, a recent graduate student of the University of Louisville, is now assistant chemical engineer for Tennessee Eastman Corp., Kingsport, Tenn.

Russell D. Yankee is now vice-president of the Jones and Loughlin Supply and Equipment Co., Fort Worth, Tex. He was previously superintendent of the Pennsylvania Salt Manufacturing Co. of Washington.

W. M. Nagle, assistant director, Eastern Laboratory, explosives department of the Du Pont Co., Gibbstown, N. J., has been transferred to Burnside Laboratory, Du Pont Co., in Penns Grove, N. J., as director.

William L. Larcamp is now employed as a chemical engineer in the engineering department of Carbide and Carbon Chemicals Corp., South Charleston, W. Va. He received a Ph.D. degree in chemical engineering from Ohio State University in June of this year.

Masood Hasan has joined Lever Bros. & Unilever Ltd., and will be given training in all phases of vegetable oil processing over the course of a year in the various factories in England. Mr. Hasan was the first trainee from Pakistan to be awarded a Regular International Fellowship. He was associated with Joseph E. Seagram & Sons, Inc., International Training Program at Louisville, Ky.

Donald F. Othmer, head of the department of chemical engineering at the Polytechnic Institute of Brooklyn, and consulting engineer, made an industrial tour this summer aimed at bringing American technical know-how to the various countries in their development of new industries. Starting on May 31 Dr. Othmer visited Honolulu, Tokyo, Hong Kong, Manila, Calcutta, Bombay, Nairobi, Johannesburg, Durban and India. Six papers written by Dr. Othmer, were delivered before a meeting of the International Congress for Agricultural Industries in Brussels. Other lands he visited, too, such as Zululand to be consulted on checking wood pulp losses, until his globe-girdling tour took him to England where he was consulted by the distillation industry as well as the builders of an experimental wallboard plant.

David A. Nelson, formerly chemical engineering assistant at the University of Wisconsin, is now with the Du Pont Co., Wilmington, Del. He is a chemical engineer in the polychemicals department.

D. Keith Starr, formerly sales engineer with W. M. Sprinkman Corp., Milwaukee, Wis., is now owner of a company known as the Crescent Milk Co. It is located in Oroville, Calif.

(More About People on page 48)

CLASSIFIED SECTION

Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance, and are placed at 15c a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line insertion free of charge per year. More than one insertion to members will be made at half rates. In using the Classified Section of Chemical Engineering Progress it is agreed by prospective employers and employees that all communications will be acknowledged, and the service is made available on that condition. Boxed advertisements one-inch deep are available at $15 an insertion. Size of type may be specified by advertiser. In answering advertisements all box numbers should be addressed care of Chemical Engineering Progress, Classified Section, 120 East 41st Street, New York 17, N. Y. Telephone ORegon 9-1560. Advertisements for this section should be in the editorial offices the 25th of the month preceding the issue in which it is to appear.

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Chemical Engineer—B.S., 28. Seven years with one major company. Assignments have included supervision of pilot plants, supervision of new plant unit startups, establishment of production and cost controls, and assistant to major executive. Primary interests—production and management. Box 9-9.

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Chemical Engineer—M.S., 30, married. Eight years' sound experience in development, pilot plant and process engineering. Desire position in smaller organization. Eastern location. Box 16-9.

Chemical Engineer—B.S.Ch.E. Northwestern Univ., co-operative program. Three years' industrial experience in food processing and paint and varnish. Prefer larger company in southern U. S. Box 17-9.

Chemical Engineer—B.Ch.E. Three years in research, two years in quality control. Extensive study in chem. eng. Single, 4-F. Desire more responsibility in engineering, production, or technical service. Prefer Ohio and vicinity or East. Box 18-9.

Chemical Engineer—B.S.Ch.E. 1948. Good scholastic record. Two years' experience with research organization in design, installation and operation of large pilot plant. Excellent references. Box 20-9.

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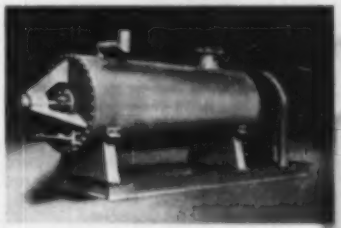

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Jack Bardin, engineer, synthetic fuels and chemicals department of Blaw-Knox Co.'s chemical plants division is in Europe to study the newest developments in these fields. Blaw-Knox has contracts with European firms for the use of techniques developed in Fischer-Tropsch synthesis, and other processes of commercial interest to U. S. industries.

Charles Davidoff, consultant for chemical and metallurgical processes, is now located at 198 Broadway, New York, N. Y.

Jorge L. Oria, formerly professor at the Institut Tecnológico y de Estudios Superiores de-Monterrey, is on indefinite leave to become assistant manager of the Departamento de Estudios Técniocs del Banco Nacional de Mexico, S. A. Mexico, D.F.

Lyle Bray, formerly in the natural gasoline department, defense plant division, Phillips Petroleum Co., Bartlesville, Okla., is now associated with the Reconstruction Finance Corp. He is in the production control section of the Office of Rubber Reserve.

H. F. Porter has recently assumed the position of chemical engineering consultant with the Du Pont Co. He was formerly associated with the American Potash & Chemical Corp.

M. O. Ricker, formerly associated with the central laboratories division of the General Foods Corp., Hoboken, N. J., has been transferred to Battle Creek, Mich. He is now in the post cereals division as technical assistant to the general manufacturing manager. At Hoboken his position was section head, engineering research laboratory.

Russell H. Blom, formerly associated with the Northern Regional Research Laboratory, Peoria, Ill., is now with the S. W. Shattuck Chemical Co., Denver, Col.

R. H. Dodd is now located in the New York office of Lummus Co. He was formerly general manager of the company's London (England) office.

B. A. Weimer is now associated with the electrochemicals department of the Du Pont Co., Wilmington, Del. He was formerly manager of development department, Industries Quimicas Brasileiras, Sao Paulo, Brazil.

H. P. Orem, formerly with the Calco Division of the American Cyanamid Co., is now with the Sloss-Sheffield Iron & Steel Co., Birmingham, Ala.

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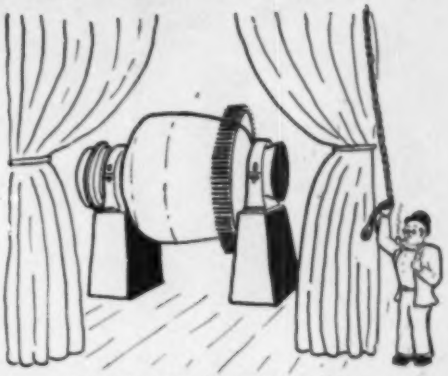

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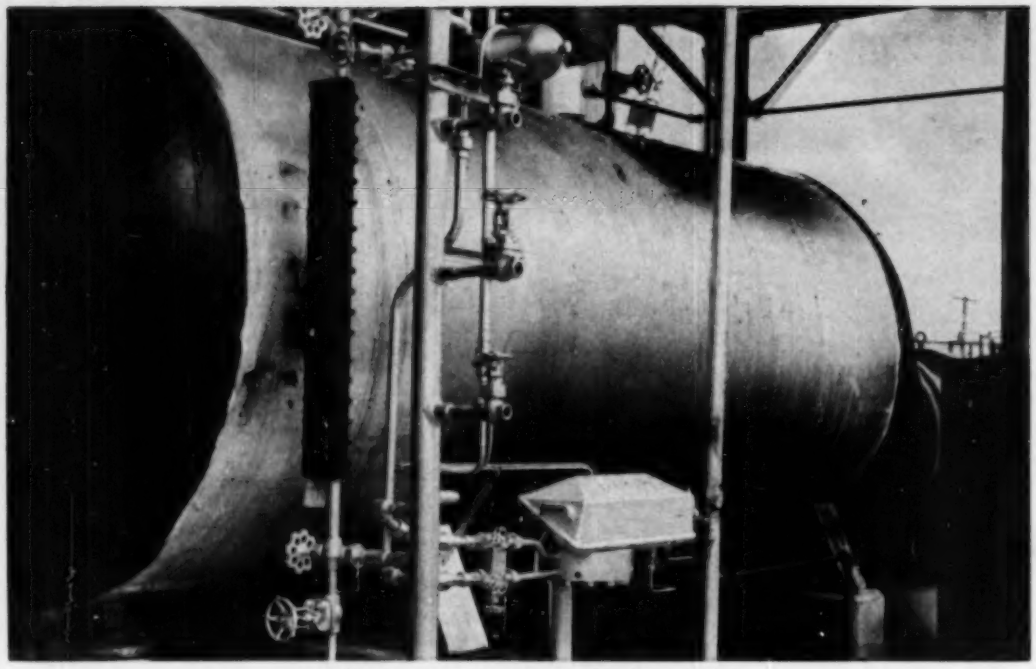

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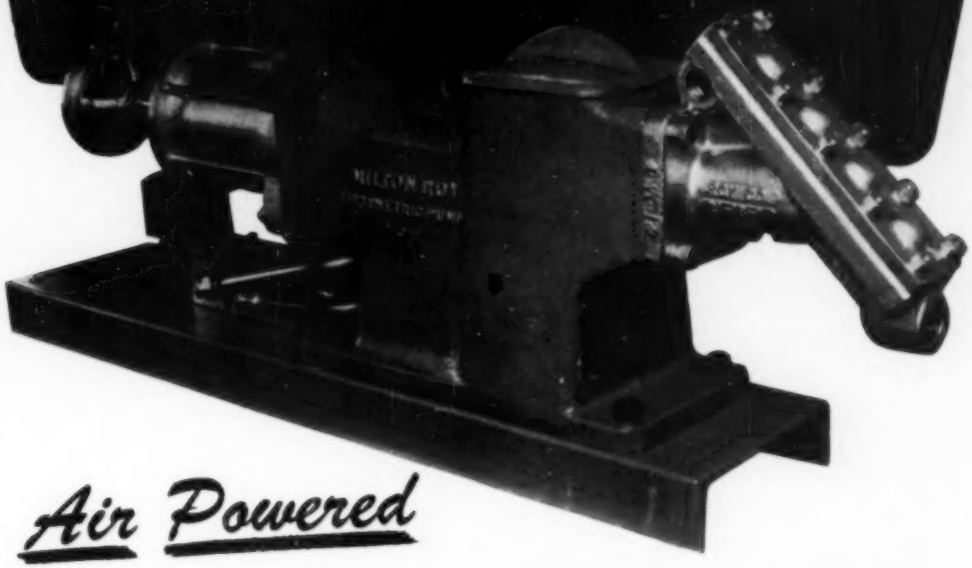

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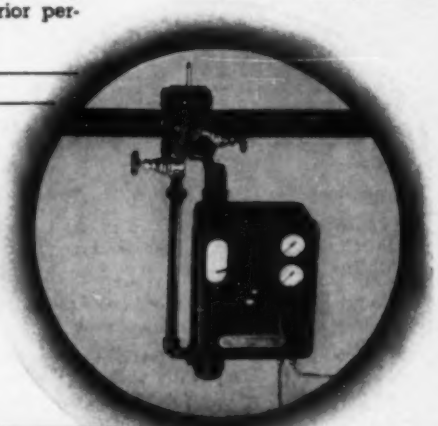

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